NAVFAC
Naval Facilities Engineering Command
Engineering Service Center

Computational Fluid Dynamics (CFD) For JLOTS Applications

JLOTS Symposium 2004

27 – 29 Jan 04

Duck, NC

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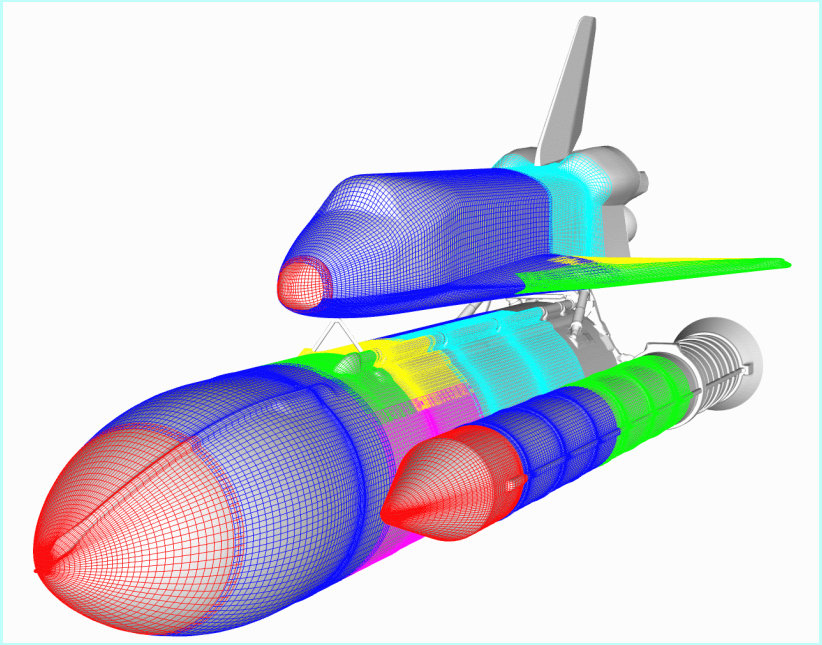
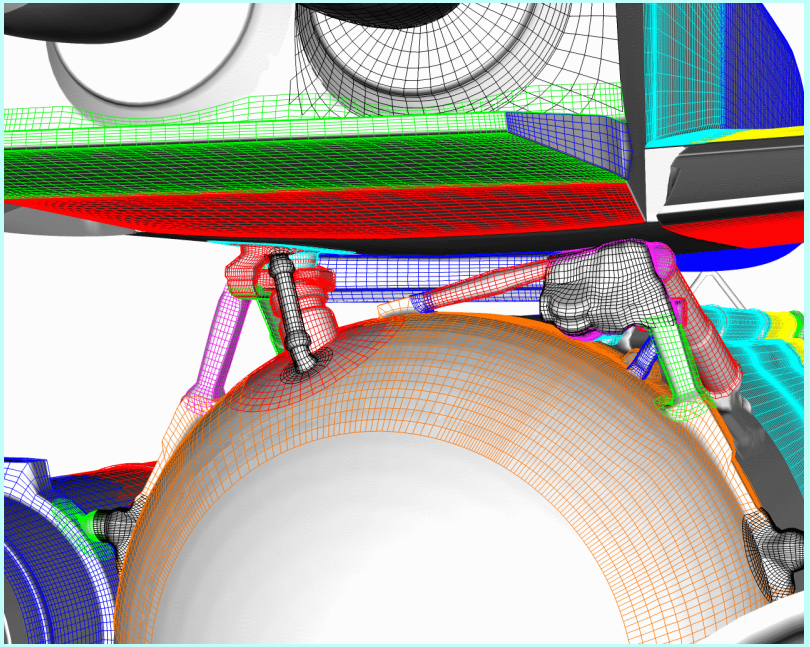
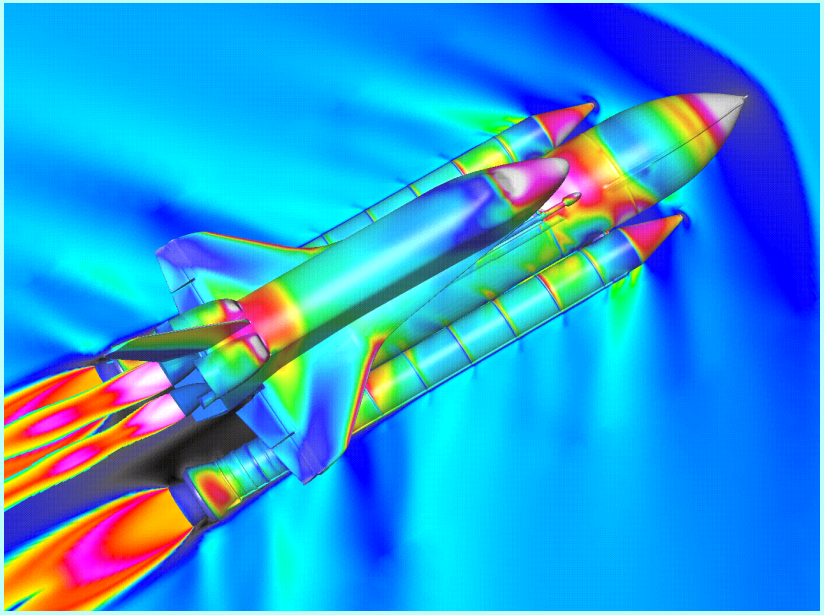
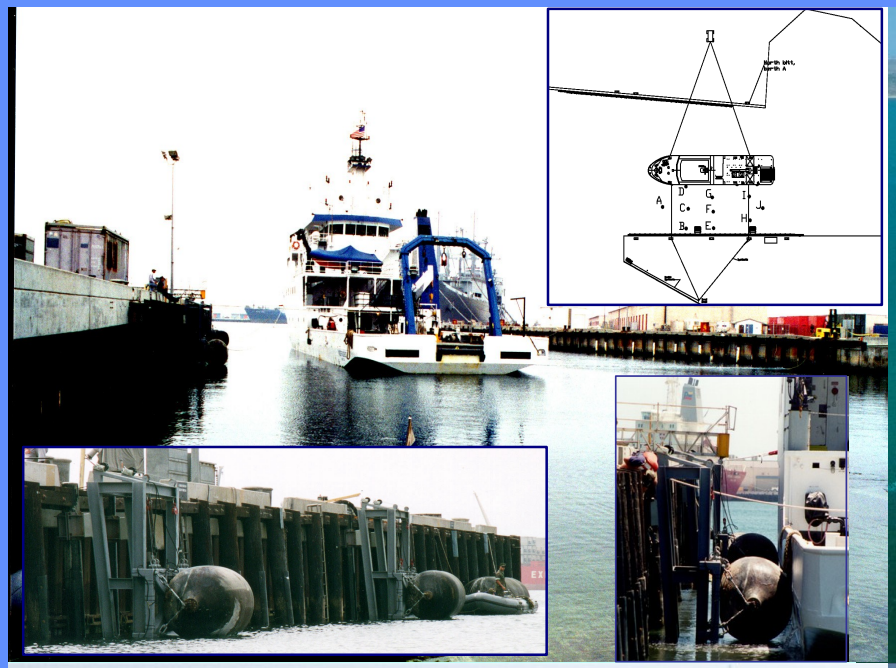


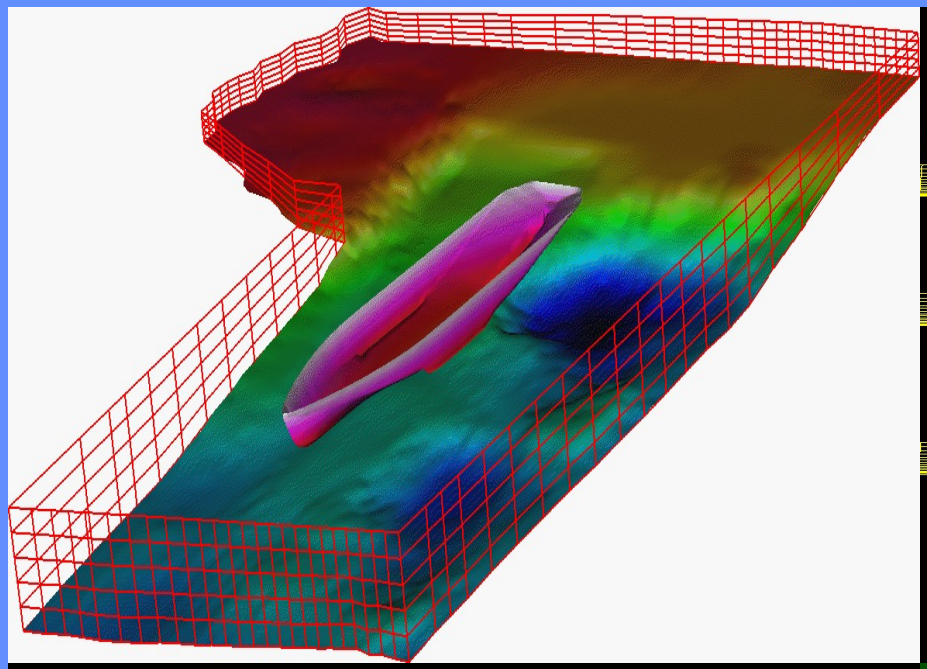


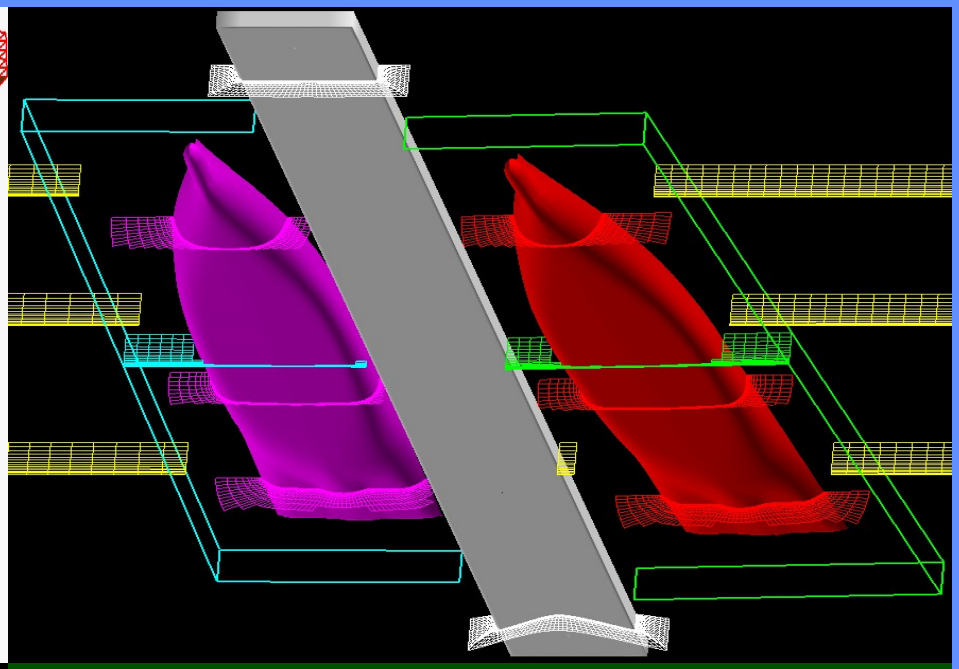


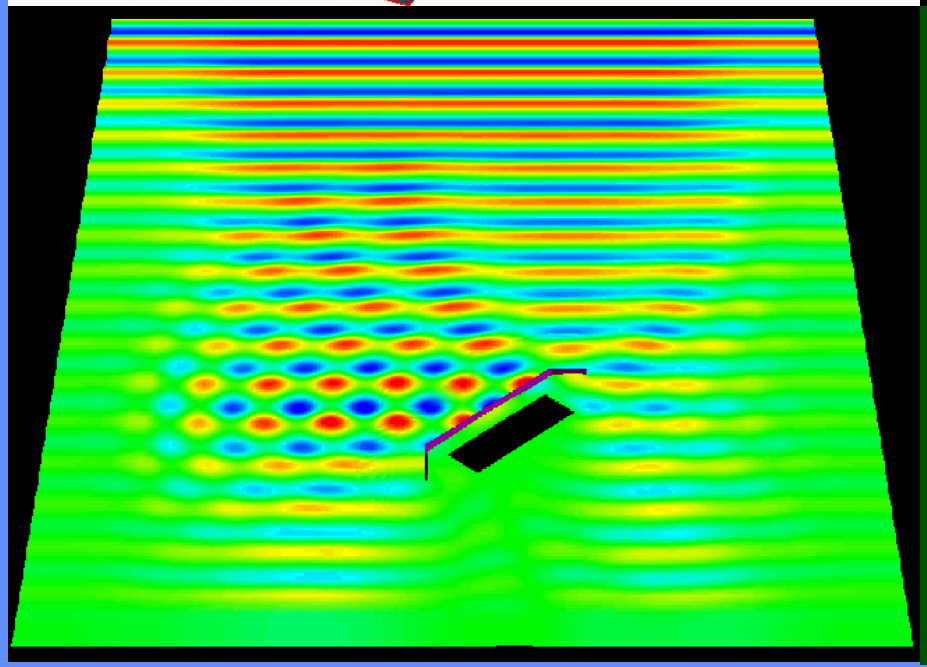
- Accuracy
- Completeness
- Cost Reduction

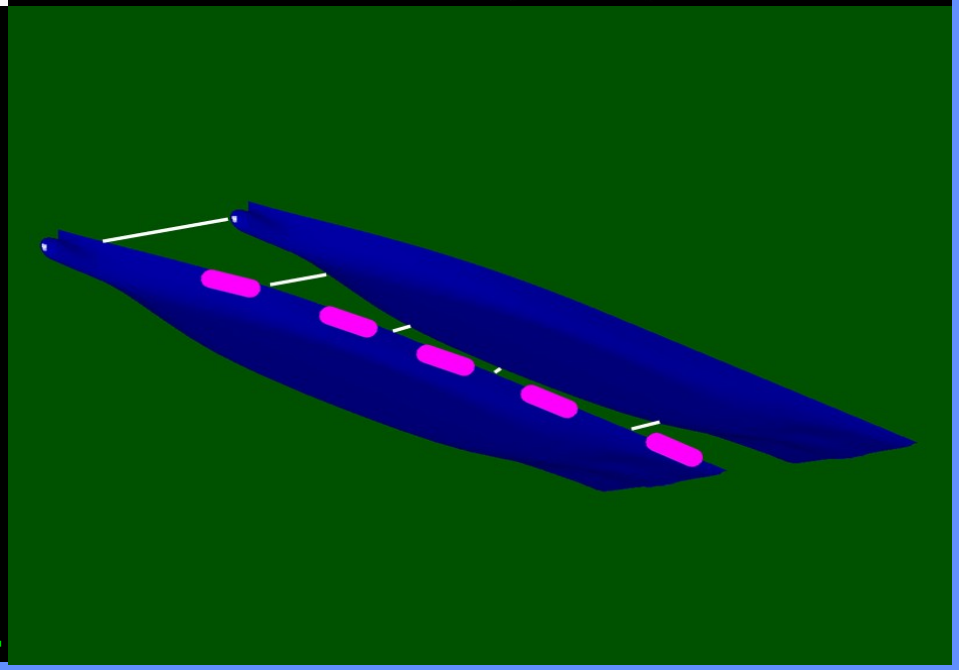


NAVAL FACILITIES ENGINEERING SERVICE CE









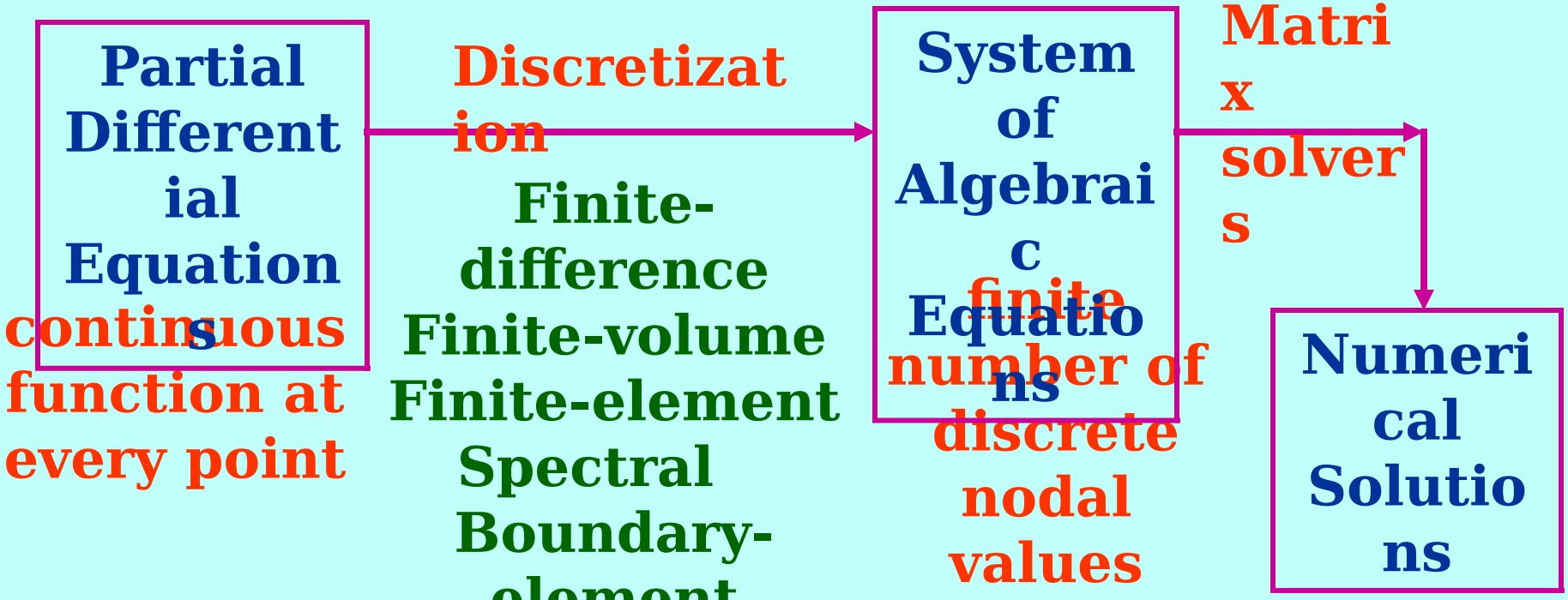
NAVAL FACILITIES ENGINEERING SERVICE CE

Fluid Mechanics

- Theoretical Fluid Dynamics
- Experimental Fluid Dynamics (EFD)
  - Wind tunnels
  - Towing tank, wave tank, & hydraulic model
  - Field experiments
- Computational Fluid Dynamics (CFD)
  - Numerical algorithms, Computers, Graphics, Animations

Overview of CFD

Discretization - Numerical Methods Auxiliary (initial/boundary) conditions



CFD model at NFESC

- RANS: Chimera, RANS viscous flow solver
- CHAMPS: Chimera Potential flow solver
- COSMA: 3D, multi-body, fully coupled motion analyzer
- Utility routines:
  - GRIDGEN (numerical grid generator, commercial code)
  - PEGSUS (data management code, USAF)
  - TECPLOT (image processor, commercial code)

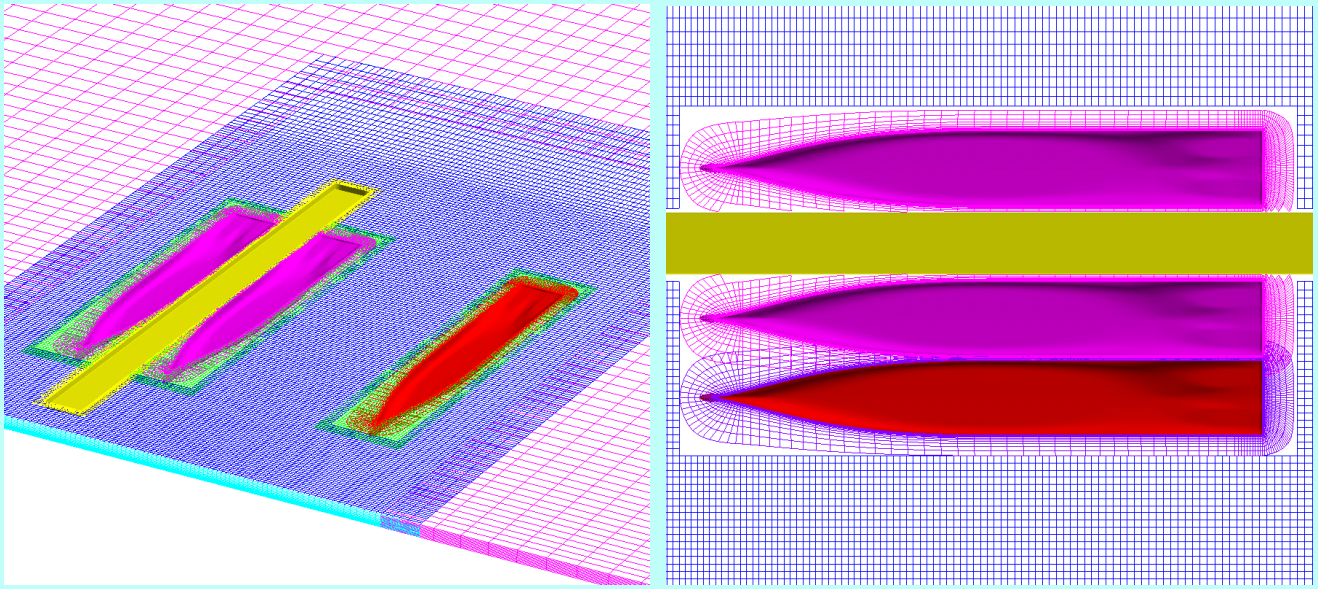
Chimera RANS Solver

- Unsteady Compressible/Incompressible Navier-Stokes Equations
- Curvilinear, Moving Coordinate System
- Chimera Domain Decomposition
- Extensive turbulence models
- Multiblock, Multigrid Flow Solver
- Interactive GRIDGEN for Composite Grids
- Embedded, Overlapped, or Matched Grids
- Automatic regridding for Moving Grids
- PEGSUS Interpolation for Composite Grids

CHAMPS

CHimera finite-Analytic Method for Potential-flow Solver

- Laplace equation for velocity potential
- Curvilinear, moving coordinate system
- Chimera domain decomposition
- Finite-analytic method
- Nonlinear free surface boundary conditions
- Data management for maximum flexibility



Chimera Grids

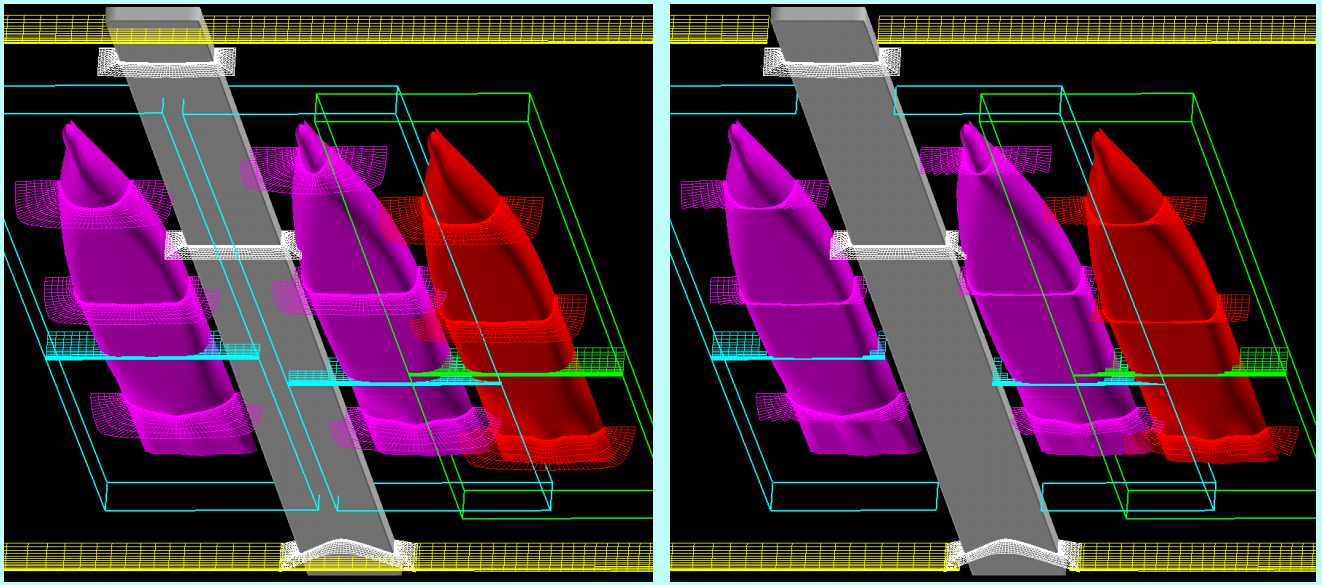
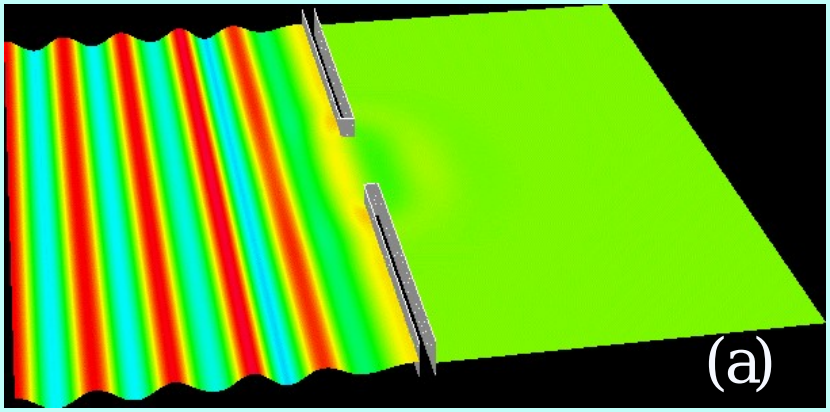
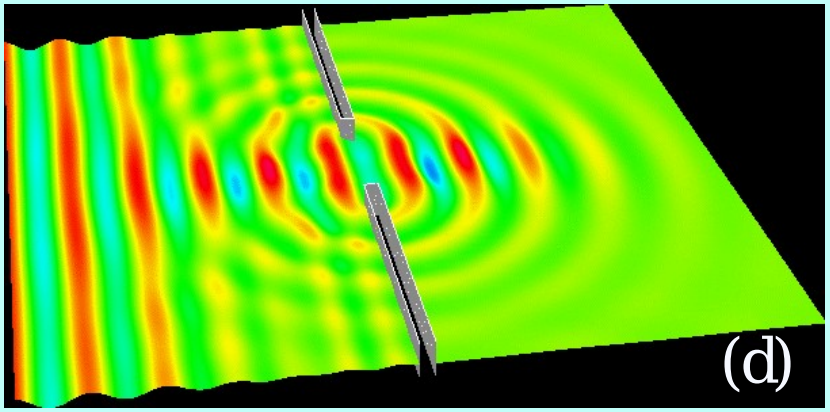
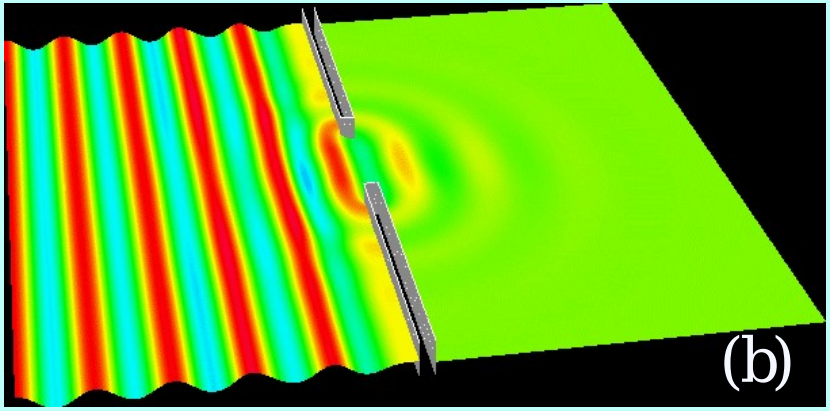


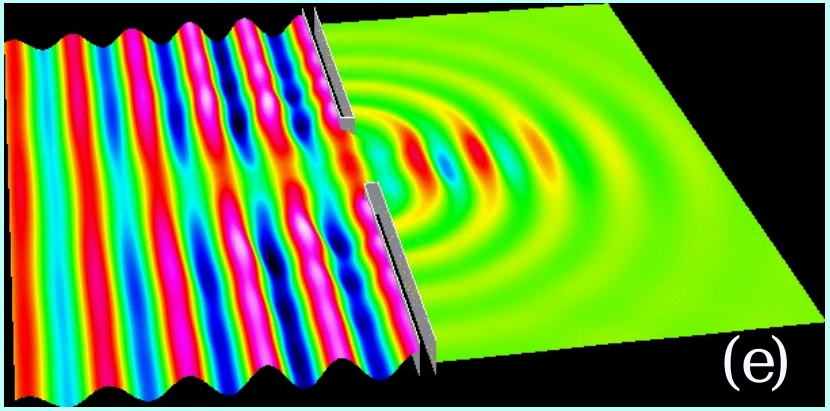
Fig. 2 – Solution domain and numerical grids

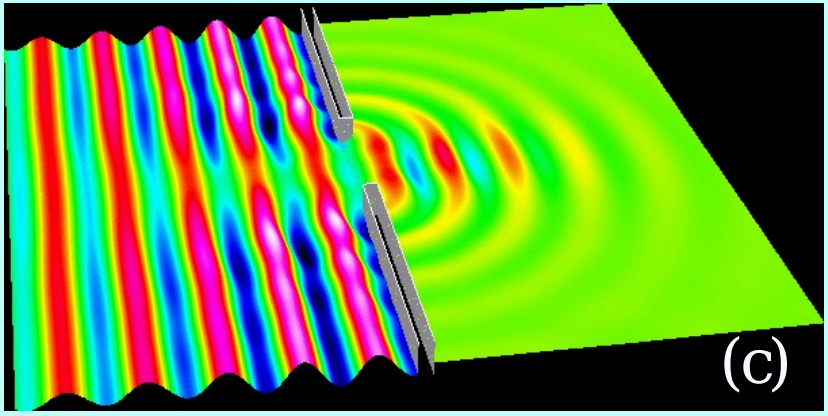
Diffraction

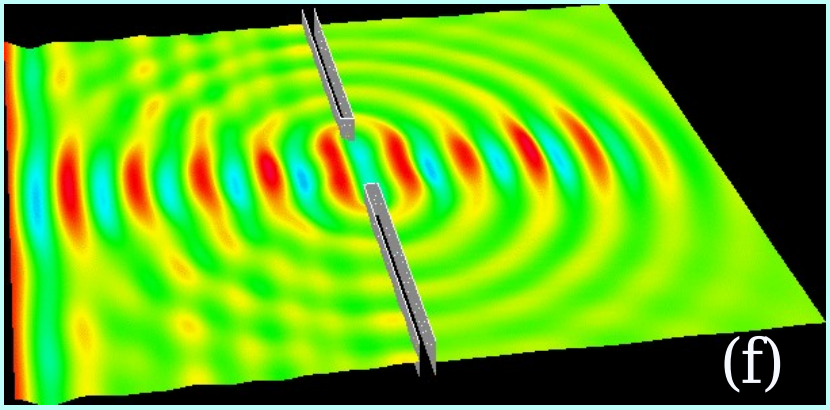




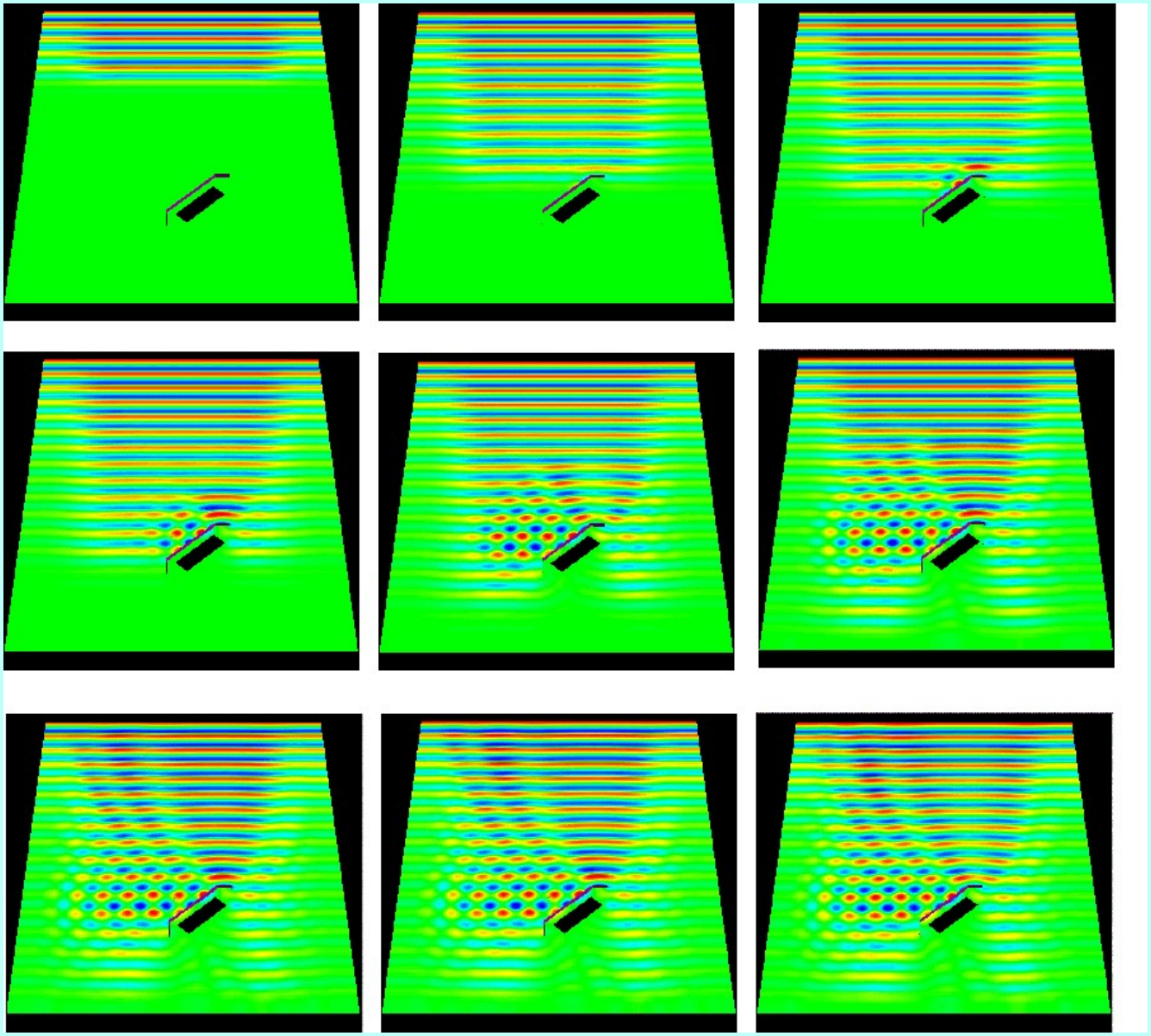




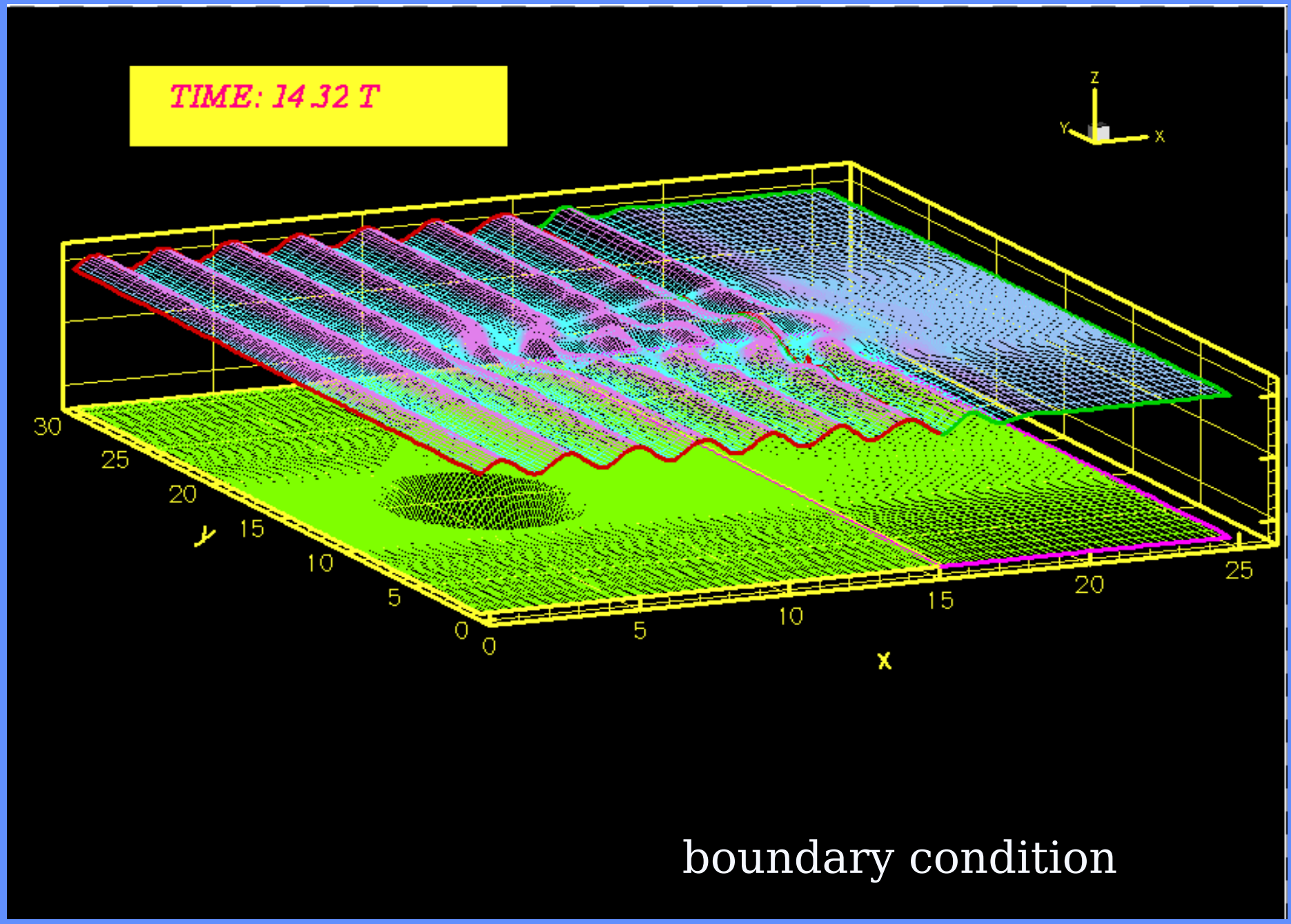




Reflection



Fisherman Wharf, San Francisco Bay

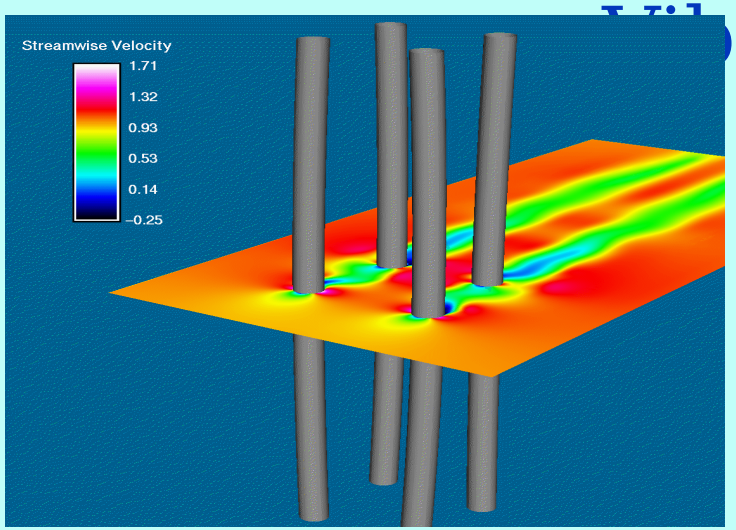


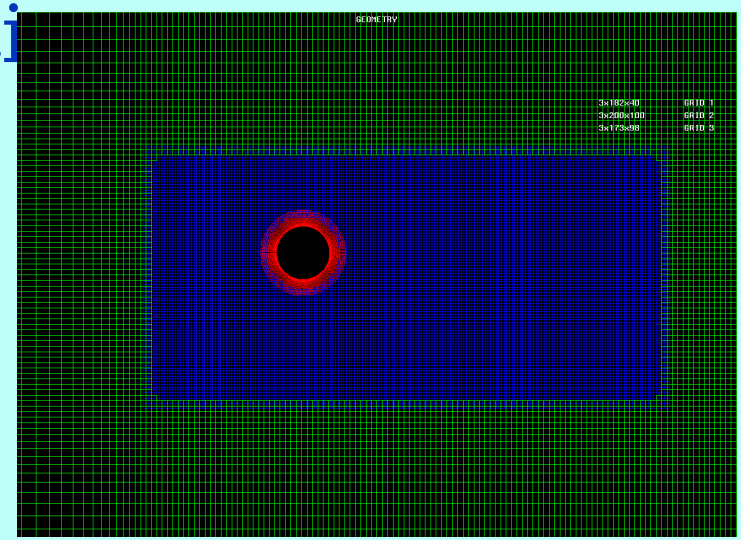
boundary condition

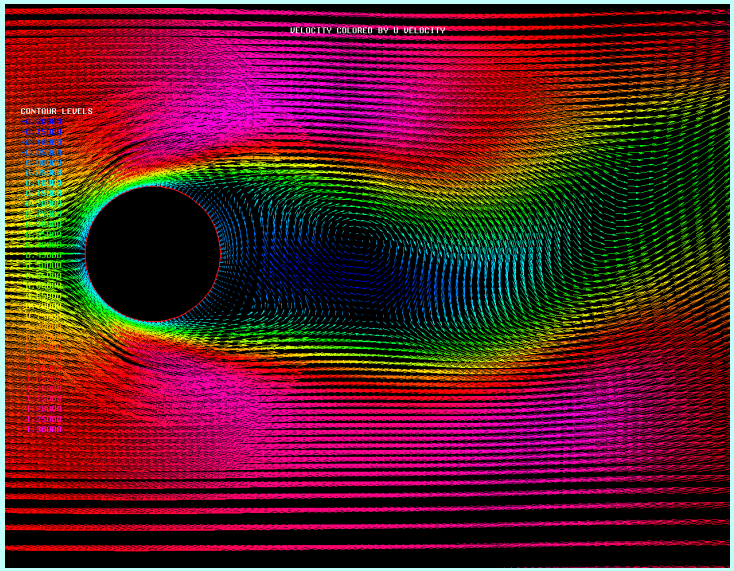
Why CFD ?

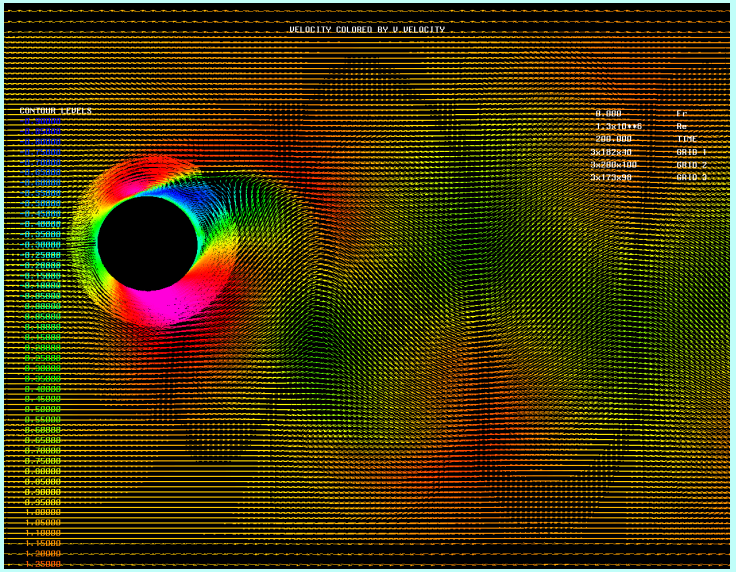
- Accuracy, completeness, & details
- Safety concerns
- Physical restraint
- Non-existence entities
- Complex system in congested water
- Uncharacteristic application
- Information expansion
- Cost, schedule, or facility constraints

Vortex Shedding and Vortex-Induced Vibrati



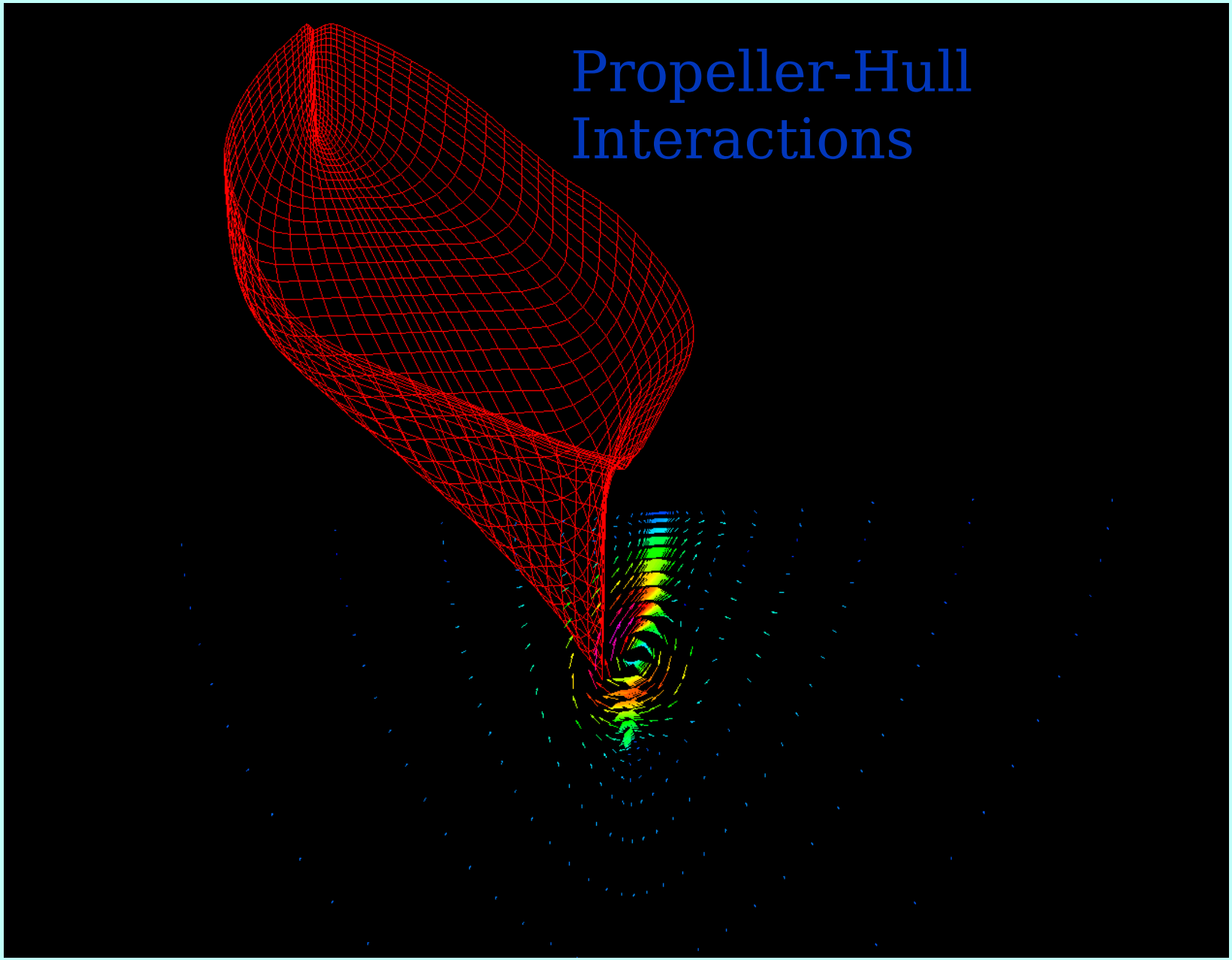






Stationary cylinder

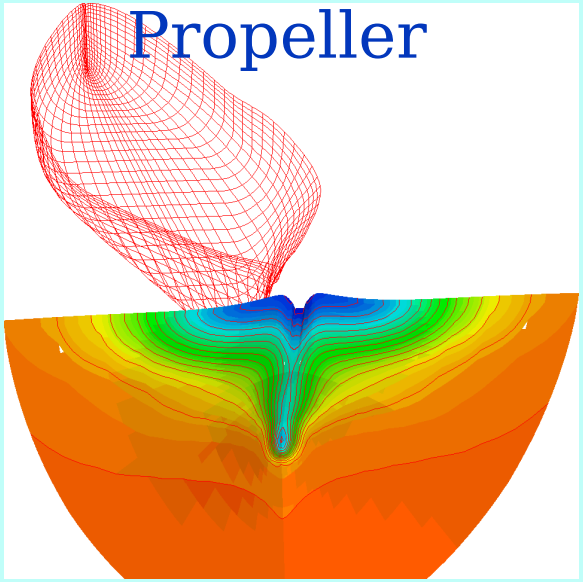
Vibrating Cylinder

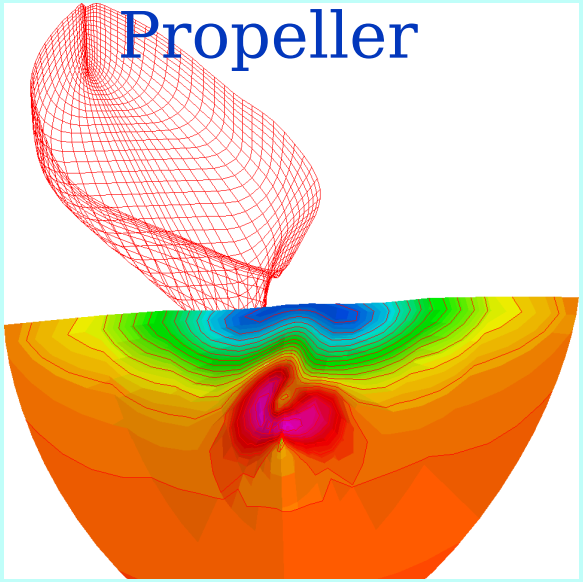

Propeller-Hull
Interactions

Without Propeller

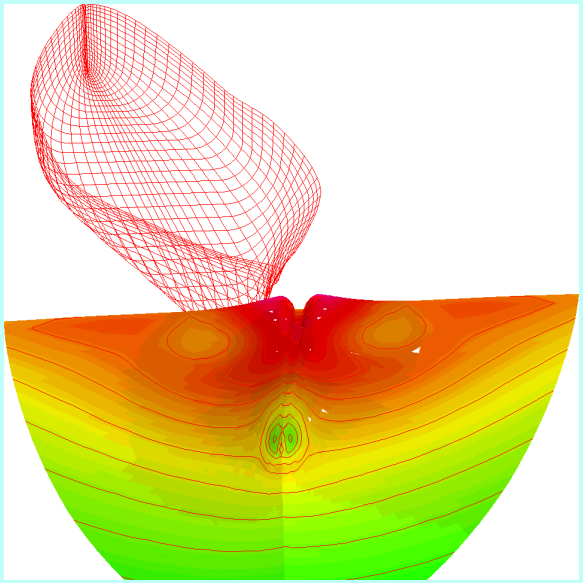
With Propeller

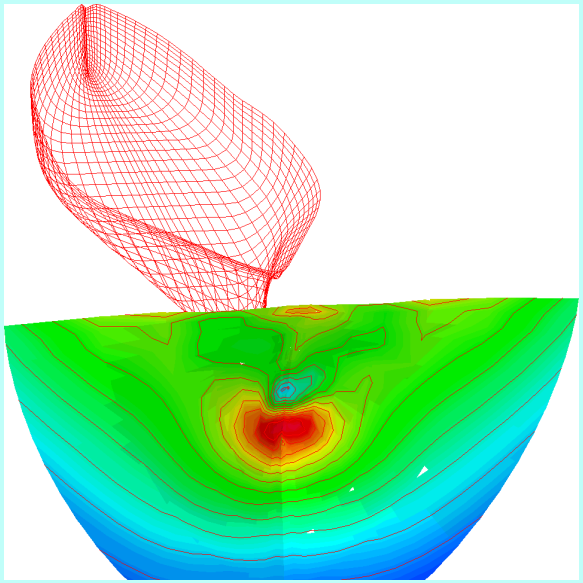
Velocity Contours

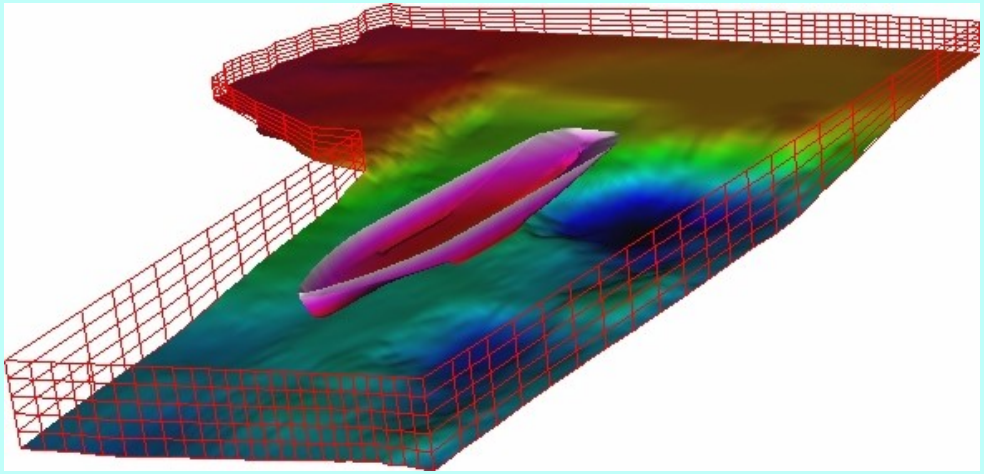


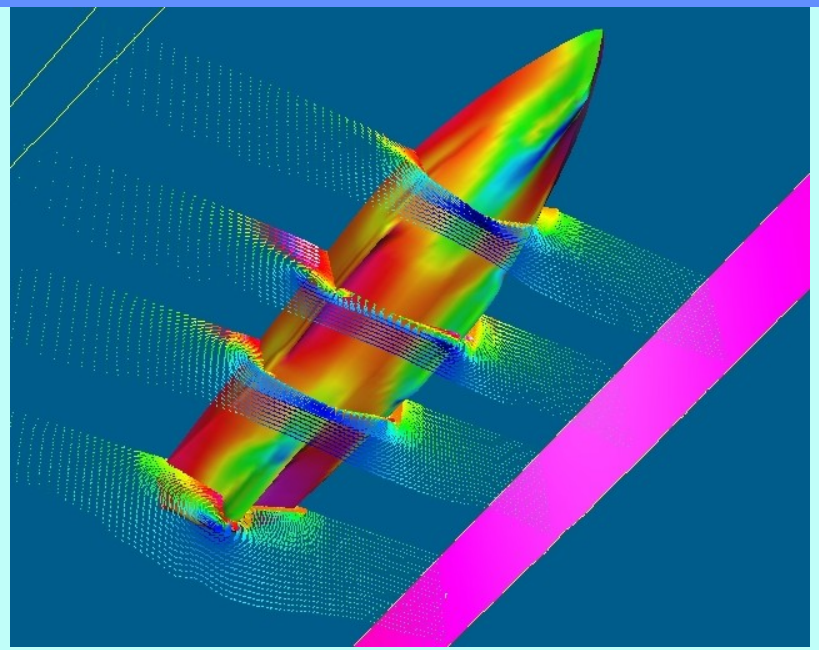


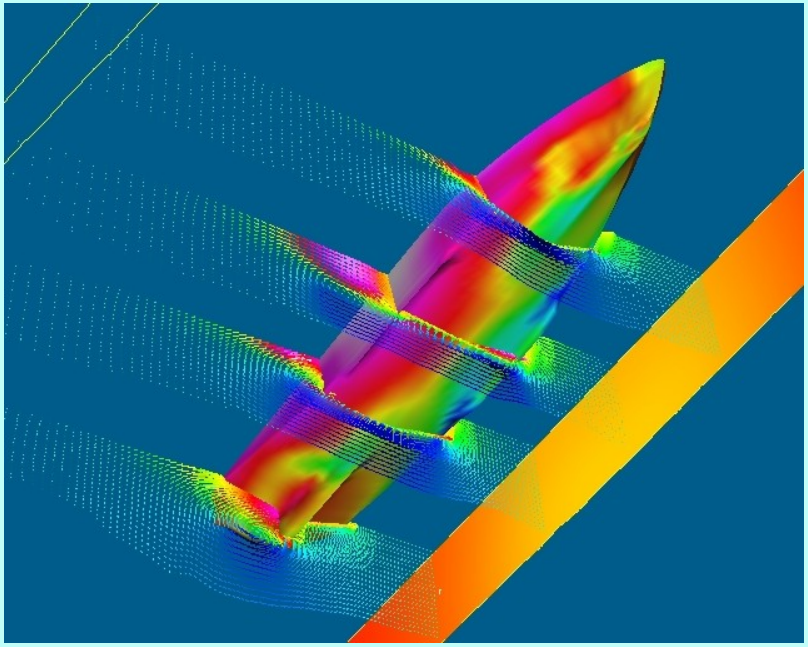
Pressure Contours

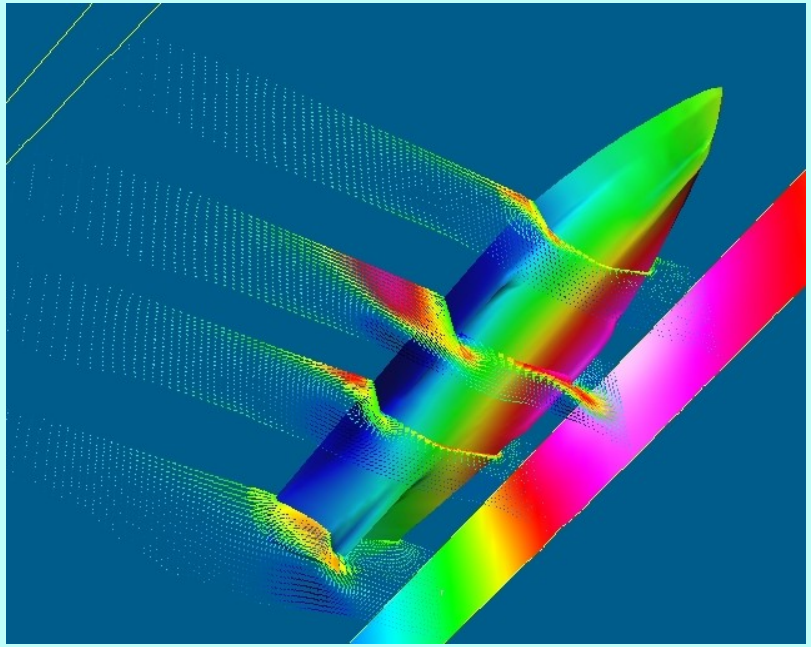




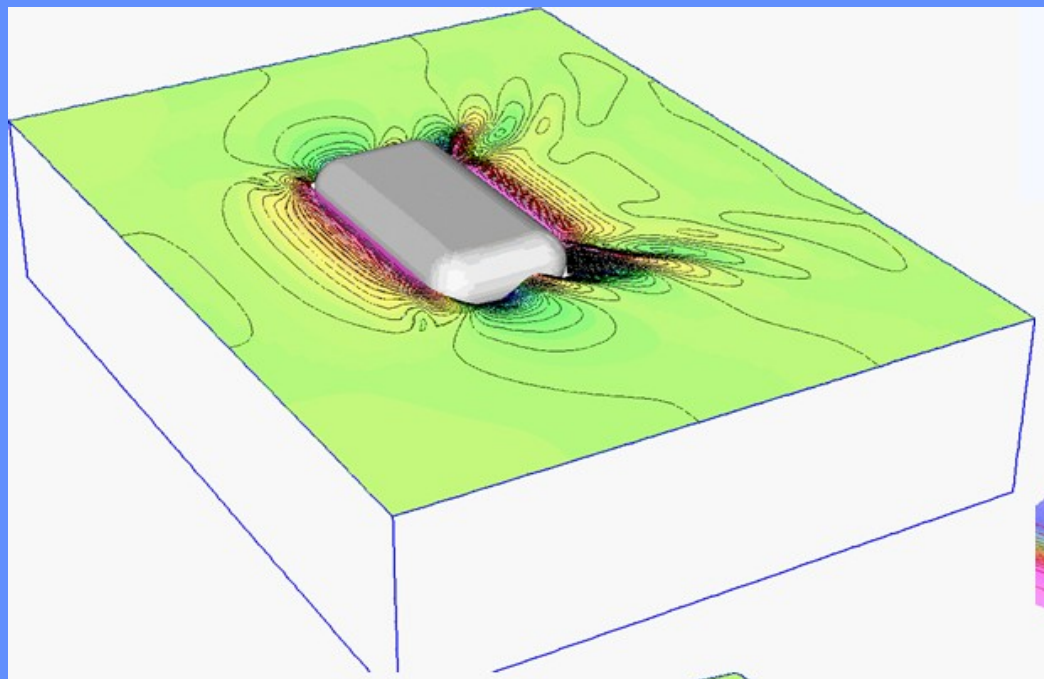


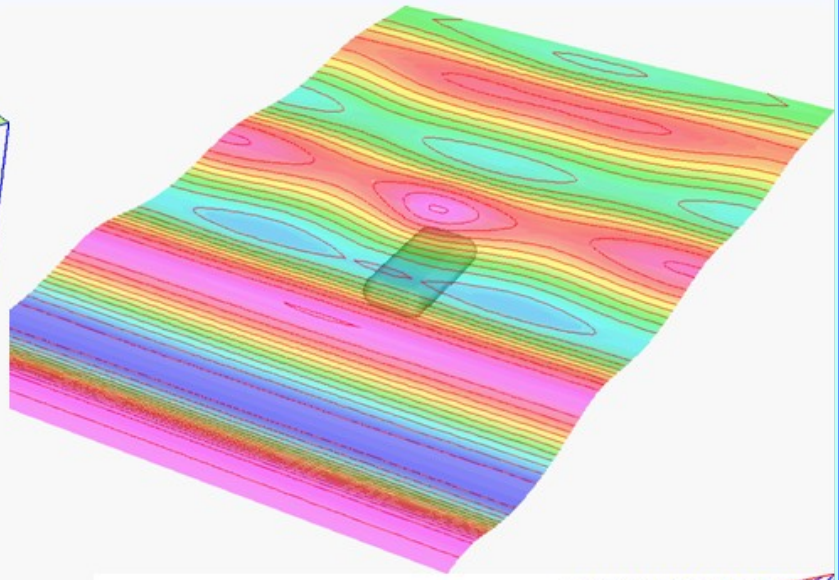


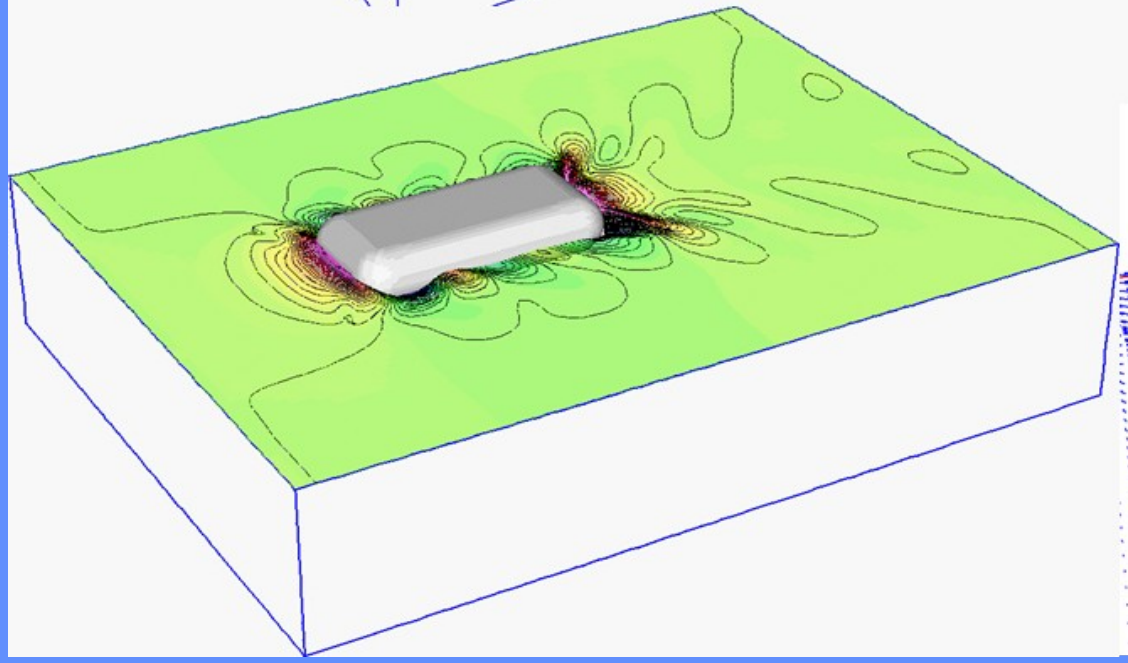


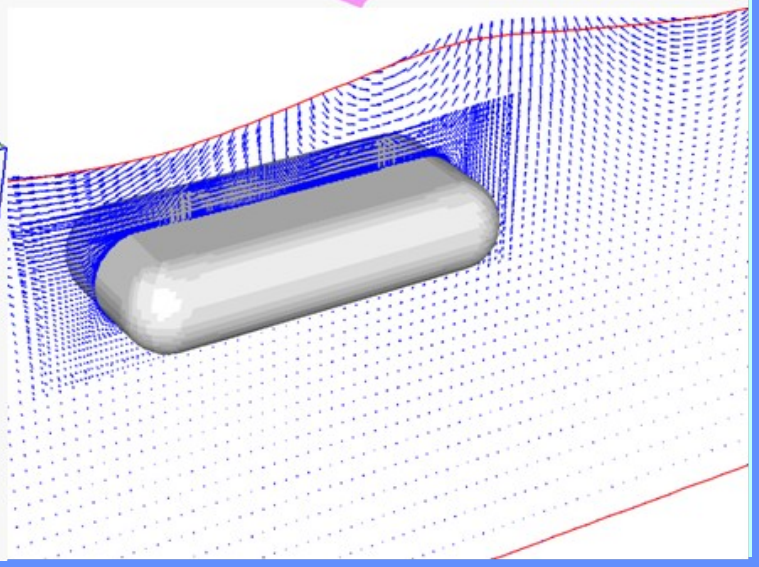


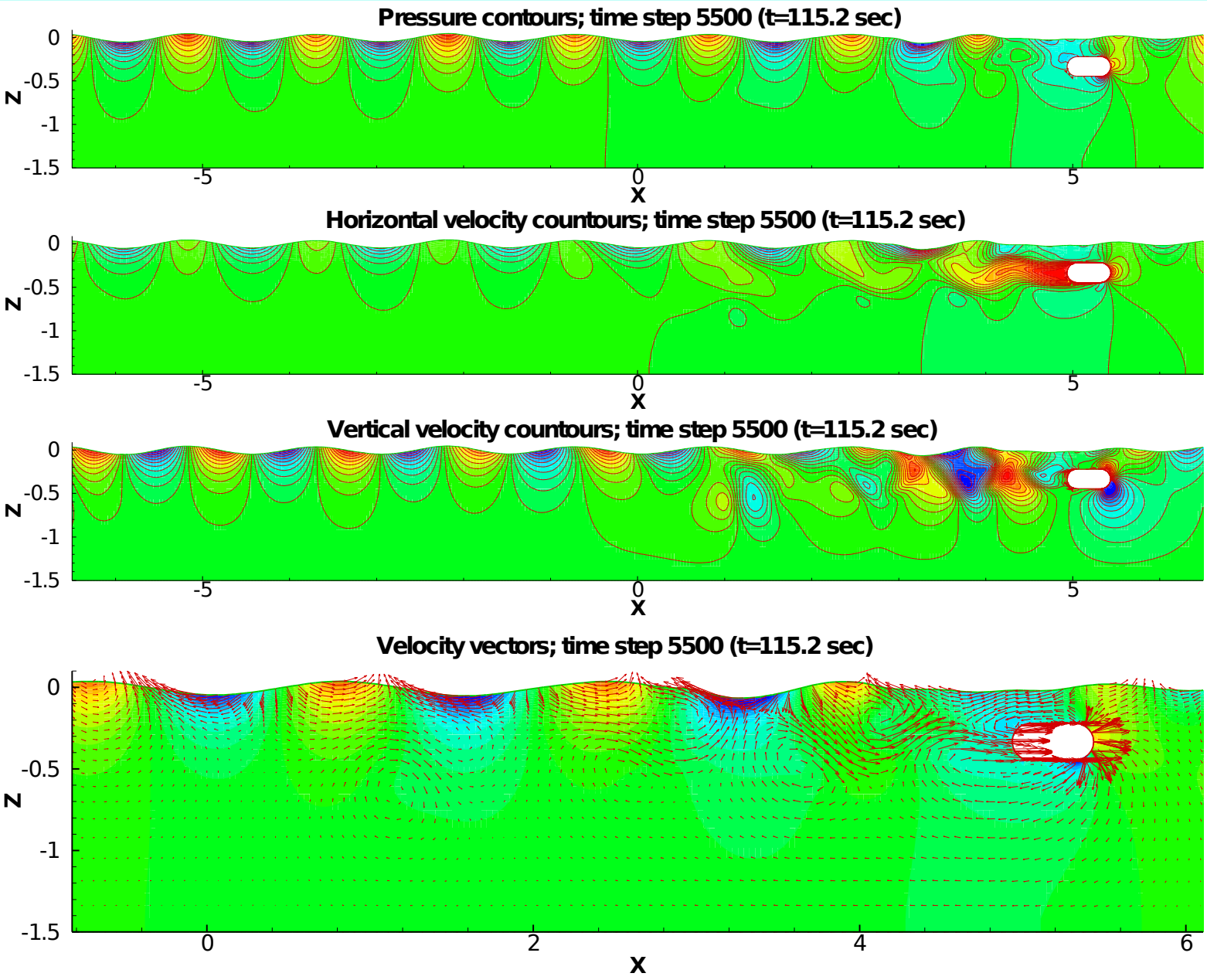
Sea Cache







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Vertical velocity countours; time step 5500 (t=115.2 sec)
Velocity vectors; time step 5500 (t=115.2 sec)
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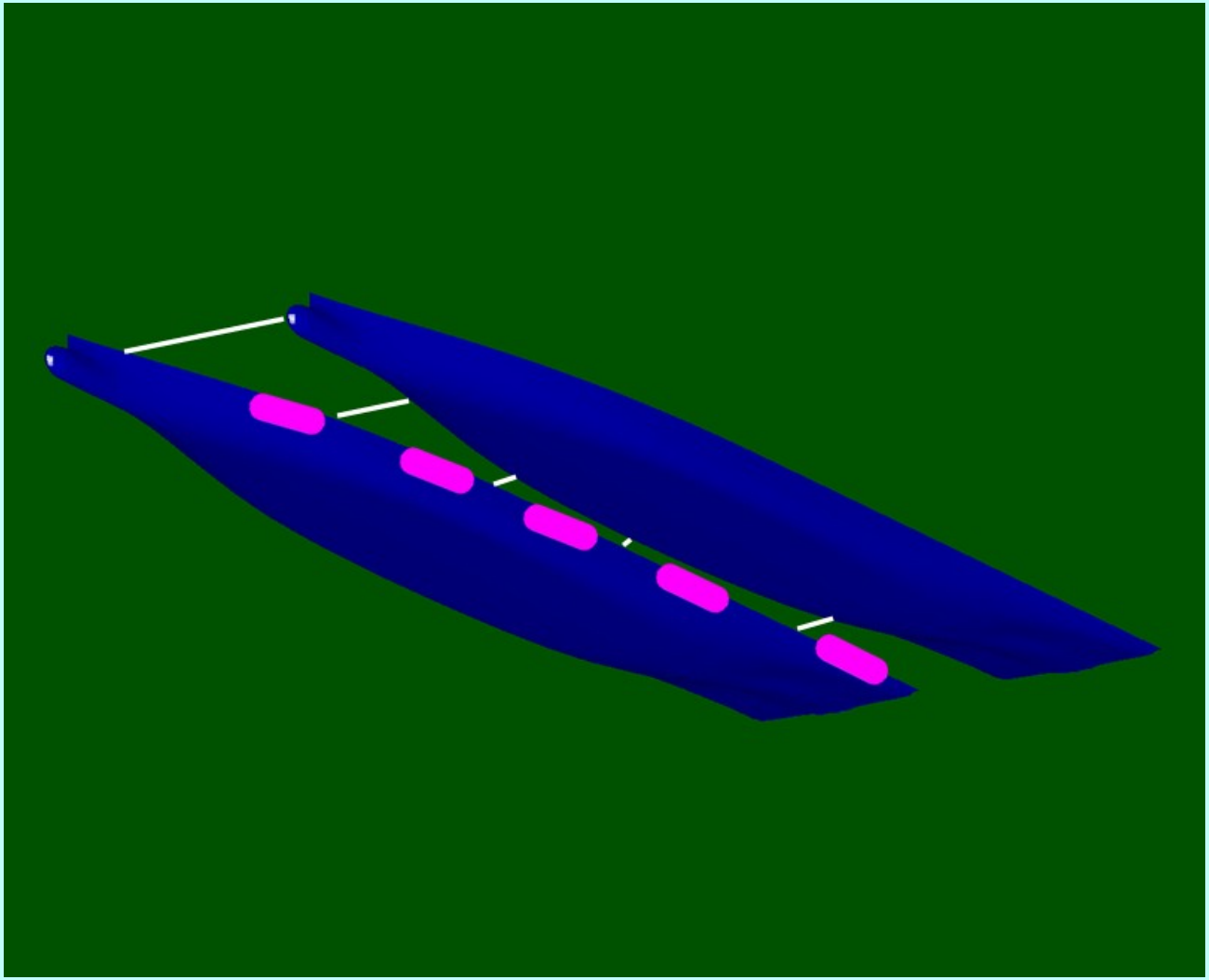
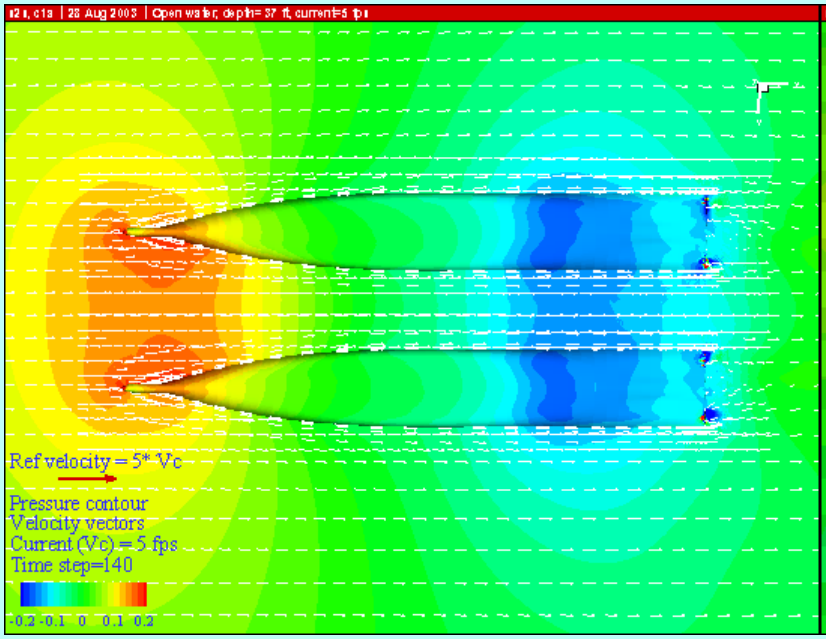
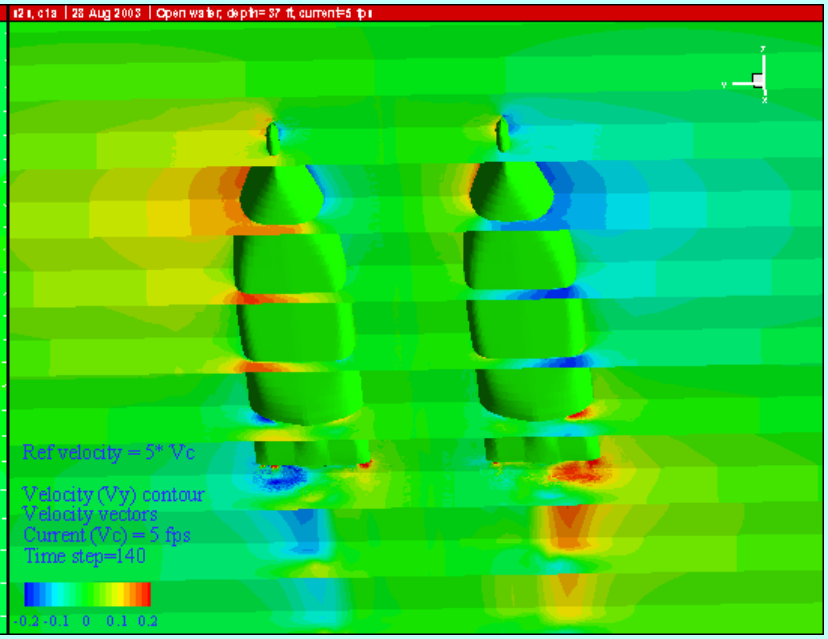
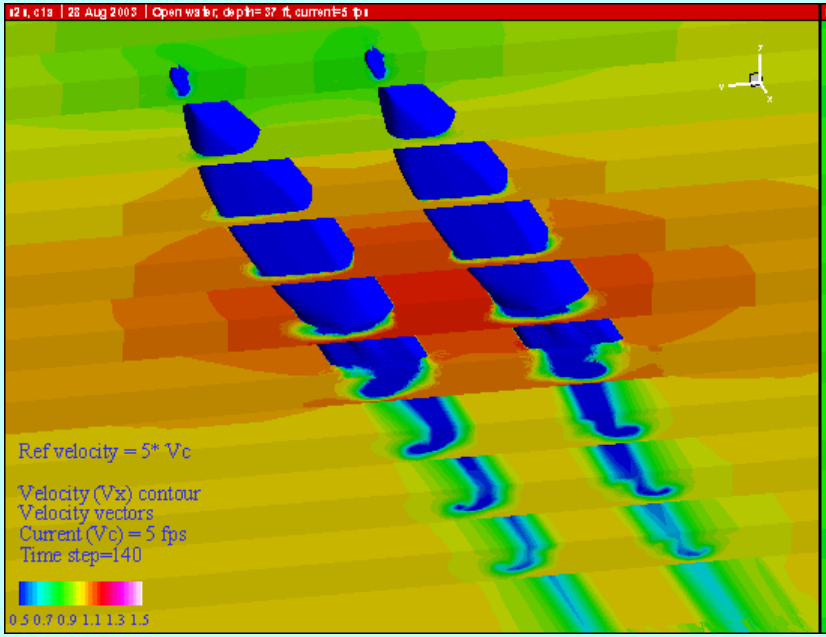
-1.5
-5
5
2
4
6

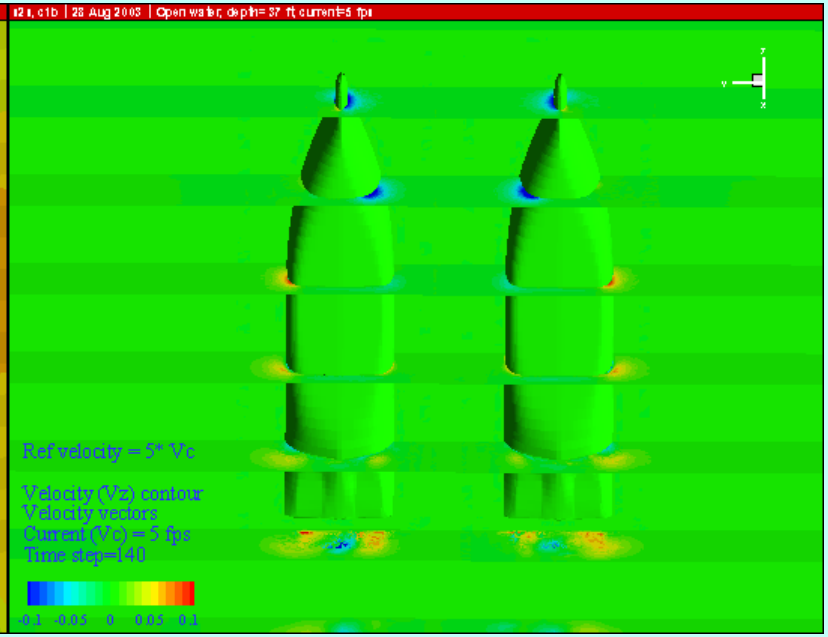
Skin-to-Skin UNREP Scenario











S2 Sc 1a

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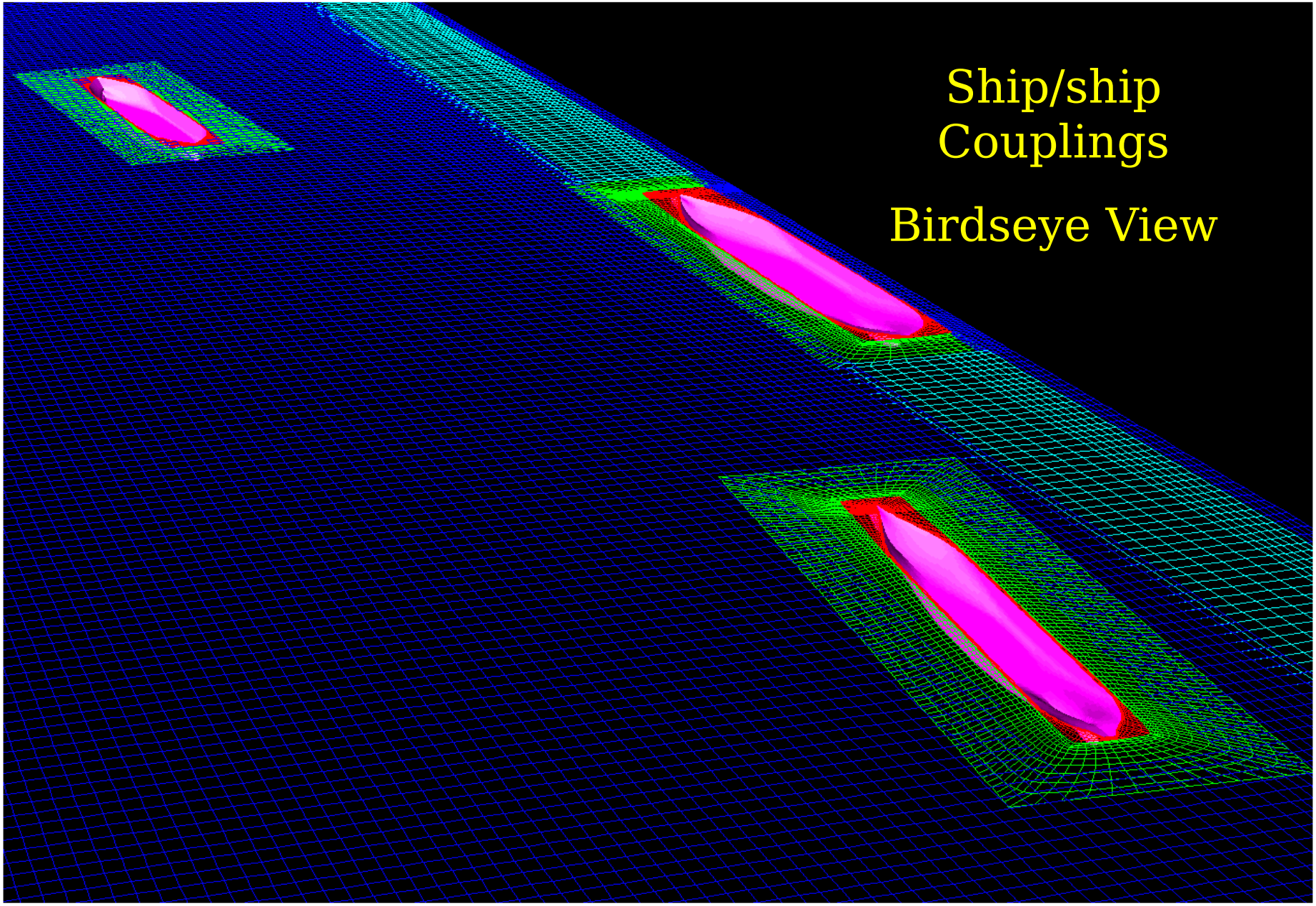
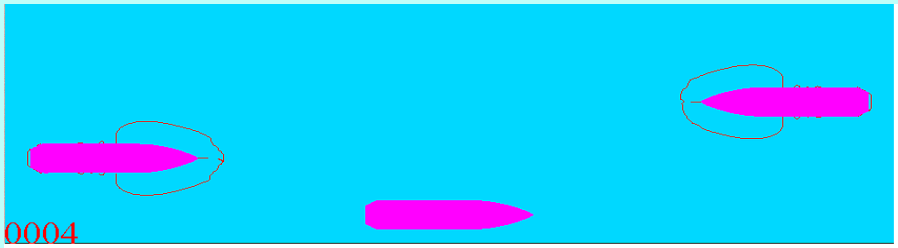

Ship/ship
Couplings
Birdseye View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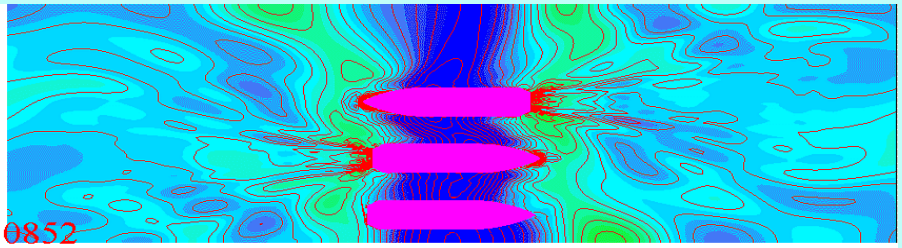
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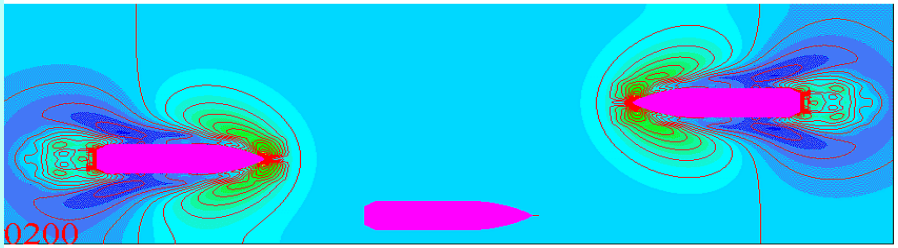
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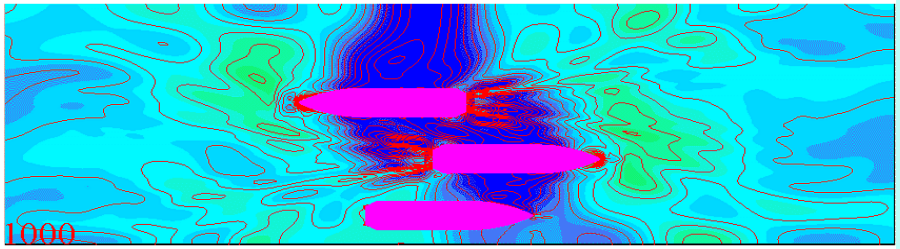
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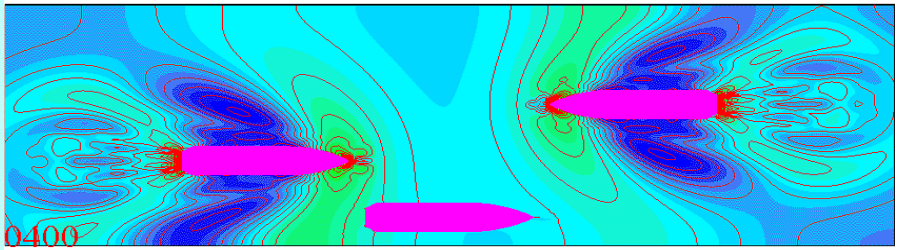
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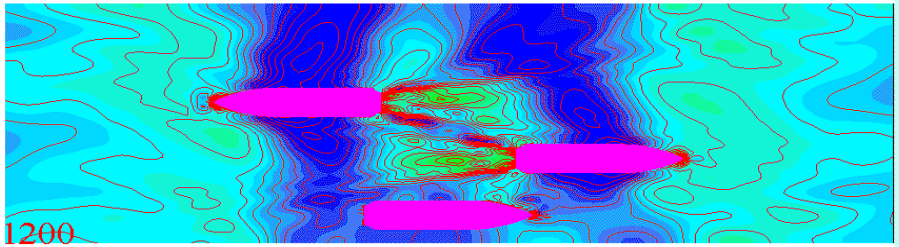
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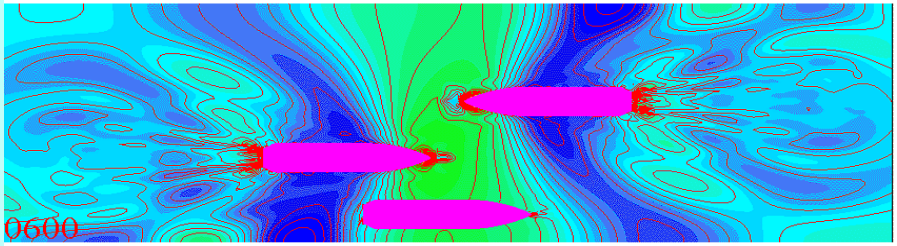
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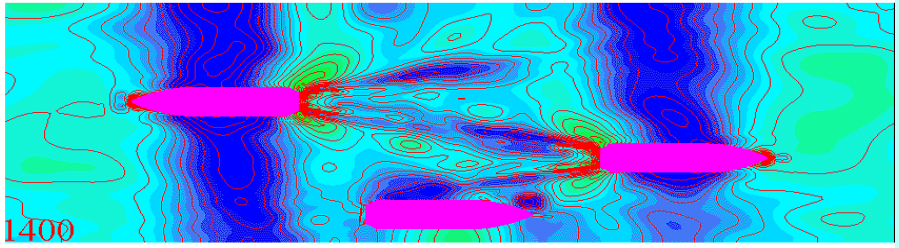
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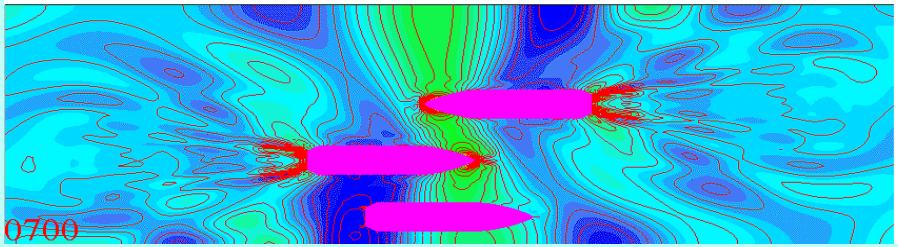
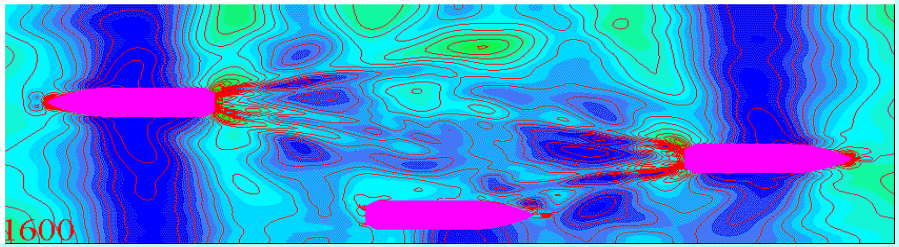
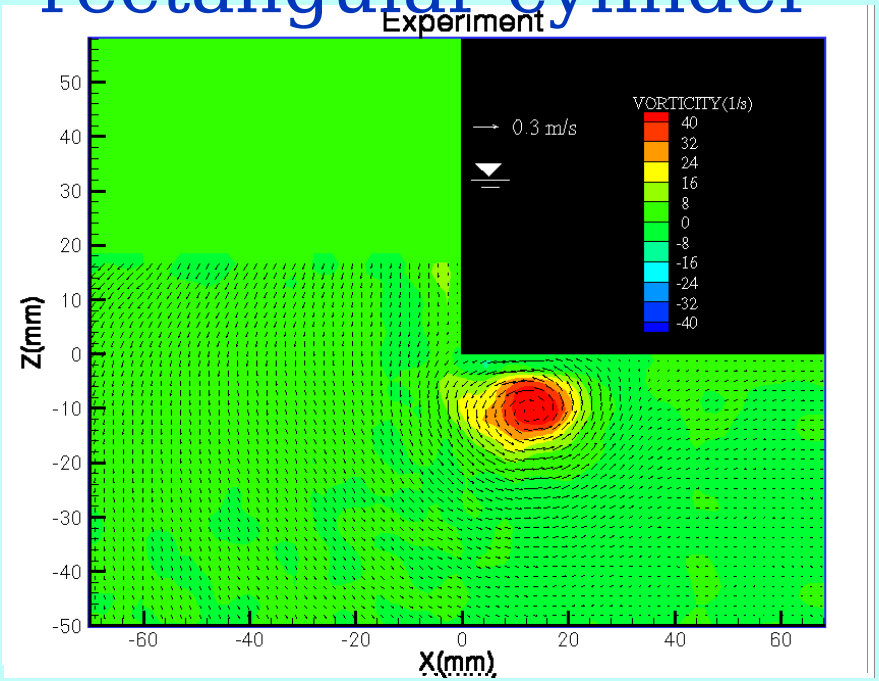
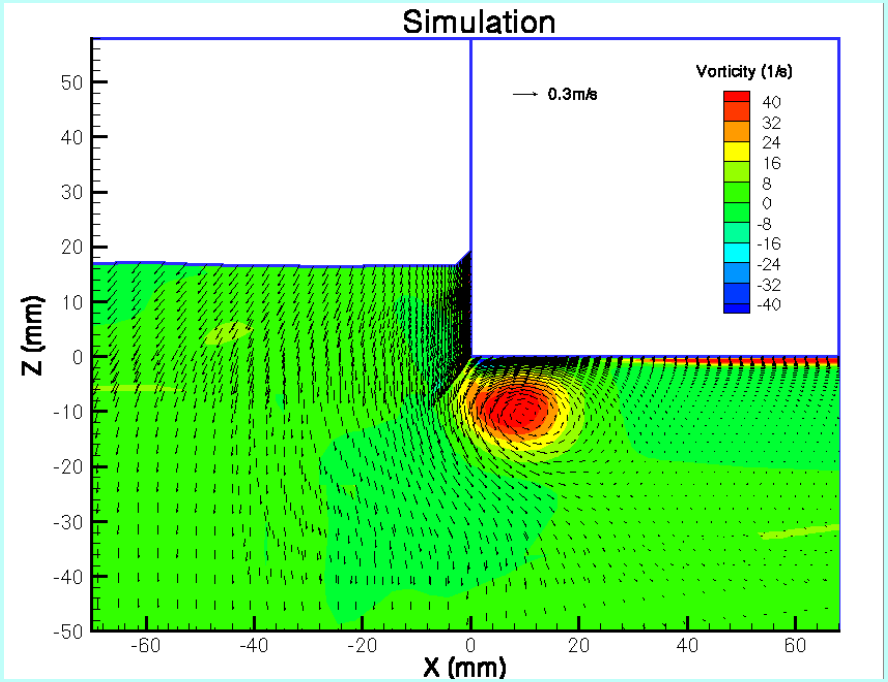

0700


1600

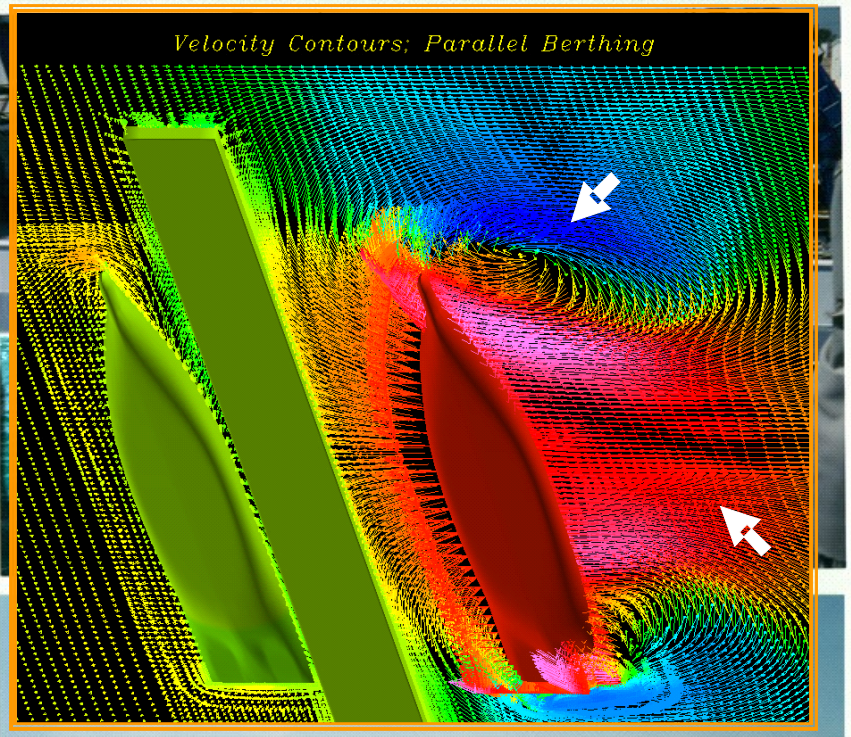
Validation 1

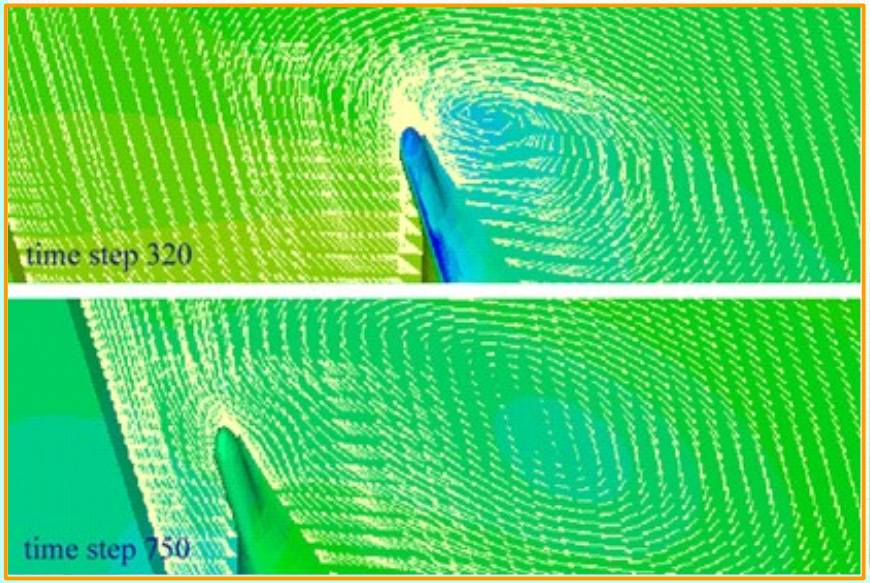
Wave induced vorticity around a rectangular cylinder

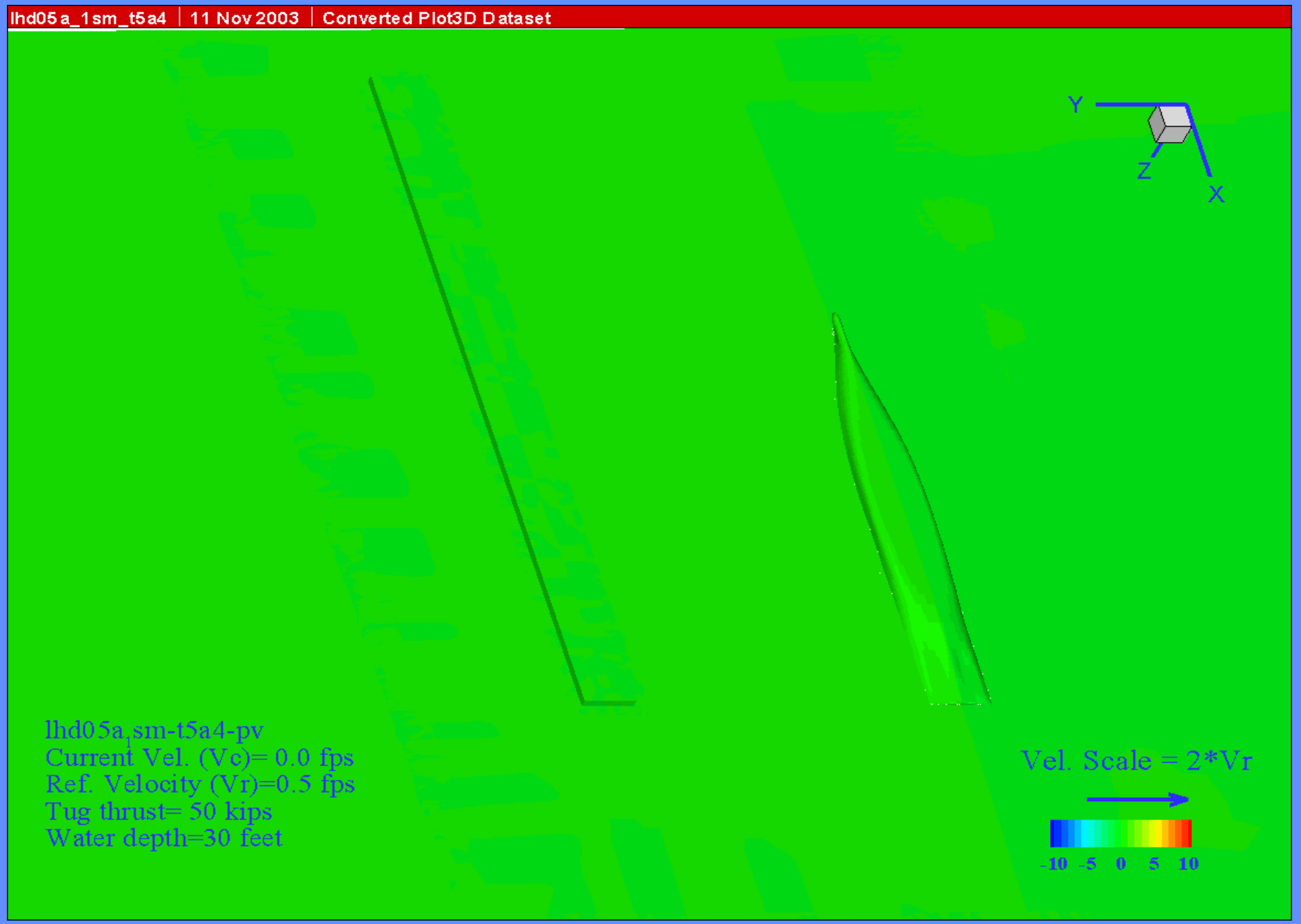




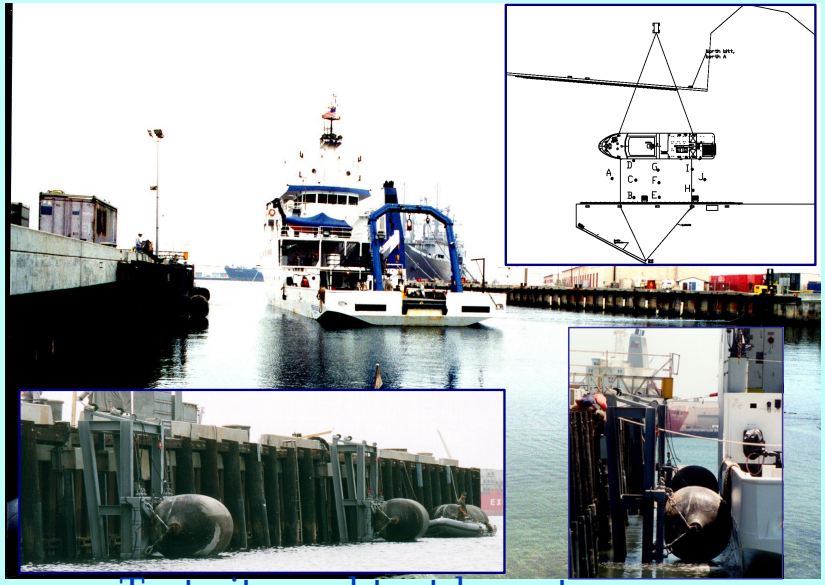
Validation 2a: flow pattern



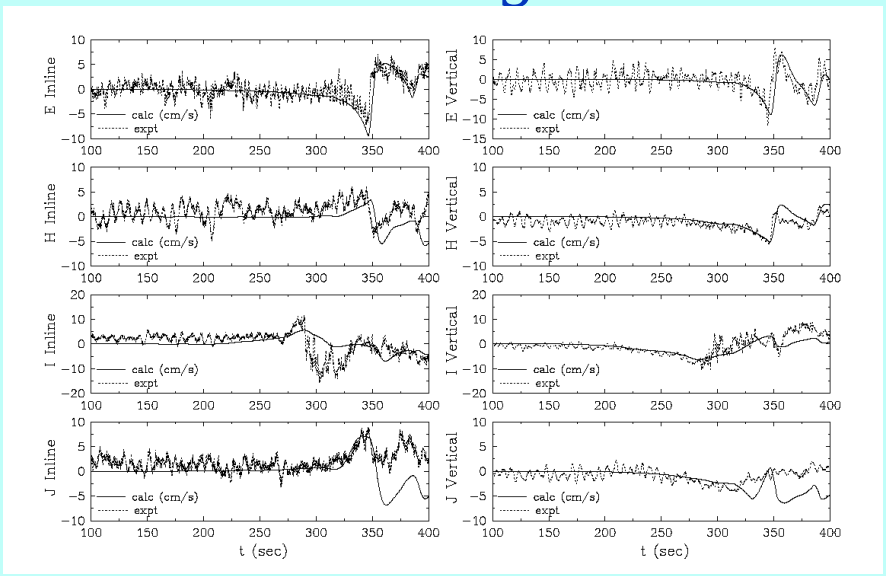



lhd05a_1sm_t5a4 | 11 Nov 2003 | Converted Plot3D Dataset
Y
Z
X
lhd05a_1sm-t5a4-pv
Current Vel. (Vc)= 0.0 fps
Ref. Velocity (Vr)=0.5 fps
Tug thrust= 50 kips
Water depth=30 feet
Vel. Scale = 2*Vr
-10 -5 0 5 10

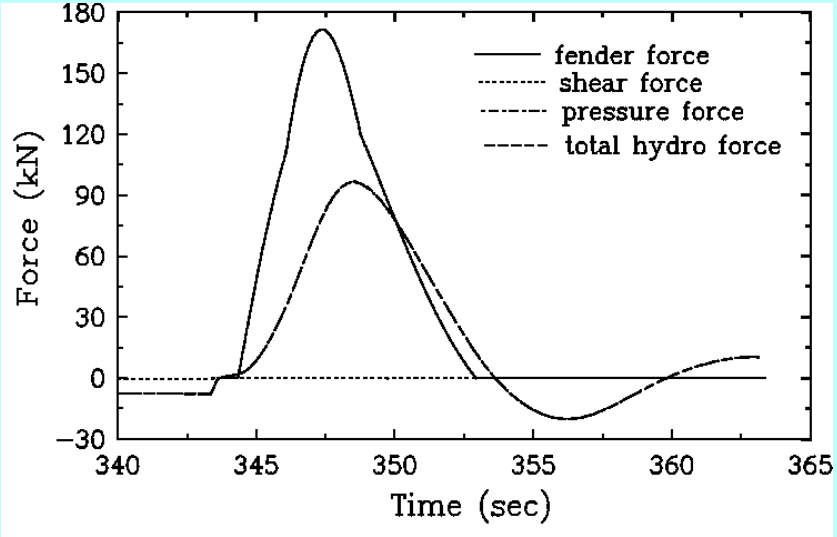
Validation 2b: Currents and berthing loads



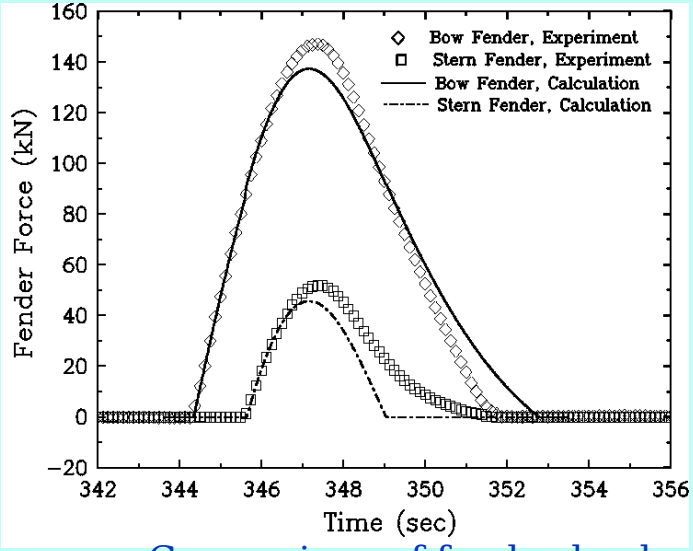
Test site and test layouts



Comparison of ship induced velocities

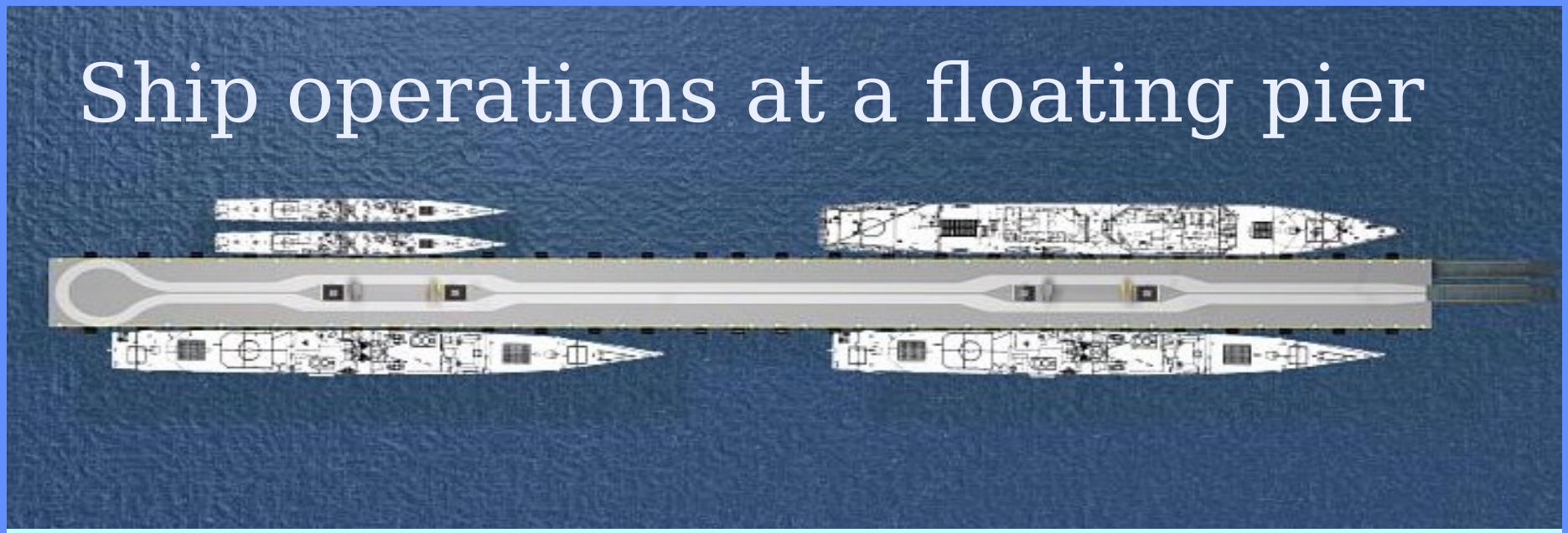


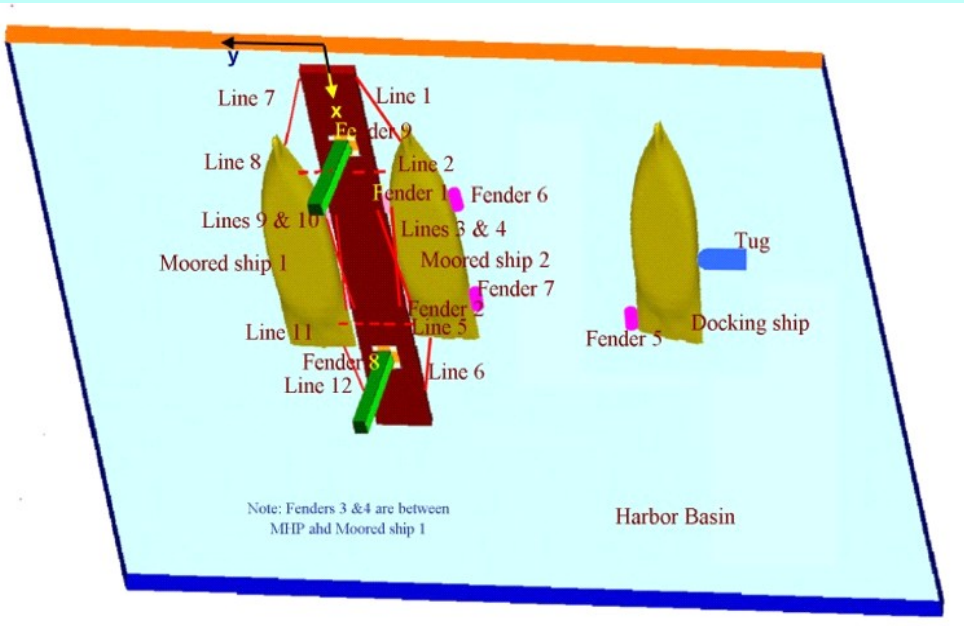
Fender loads and hydrodynamic forces



Comparison of fender loads

Ship operations at a floating pier

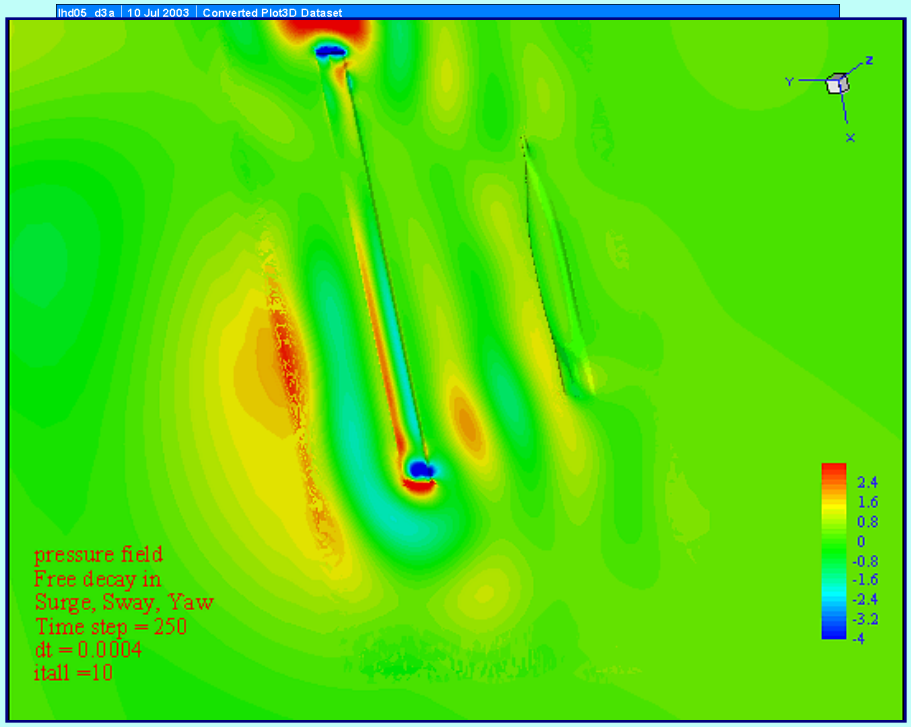


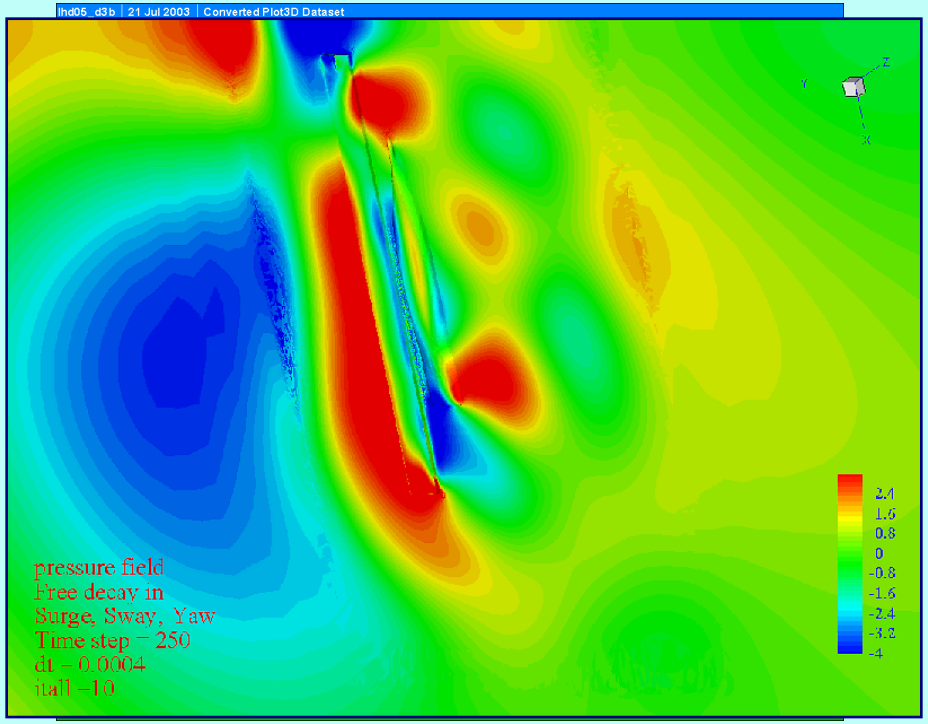


Free Decay

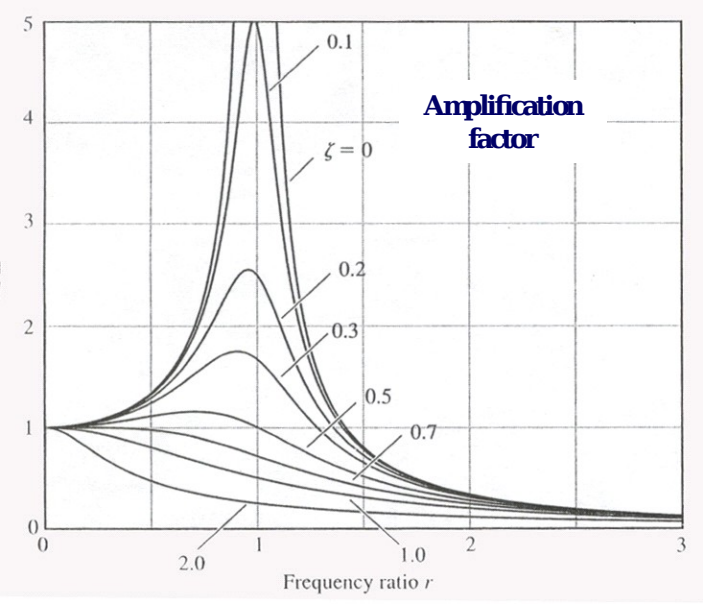
Purposes:

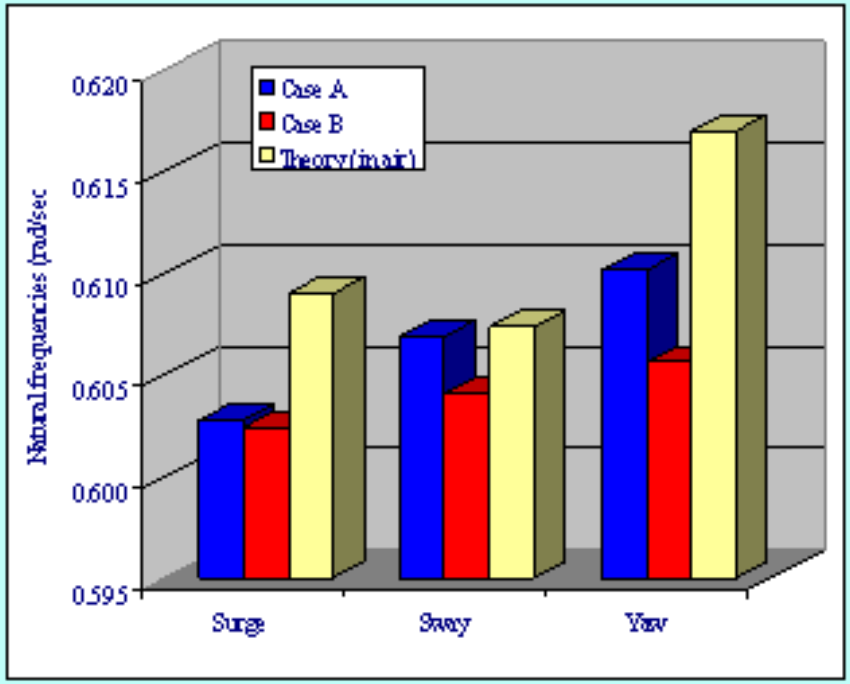
- Quantify dynamic characteristics of MHP: resonant frequency & damping
- Explore the influence of vicinity structures to the motion characteristics of MHP



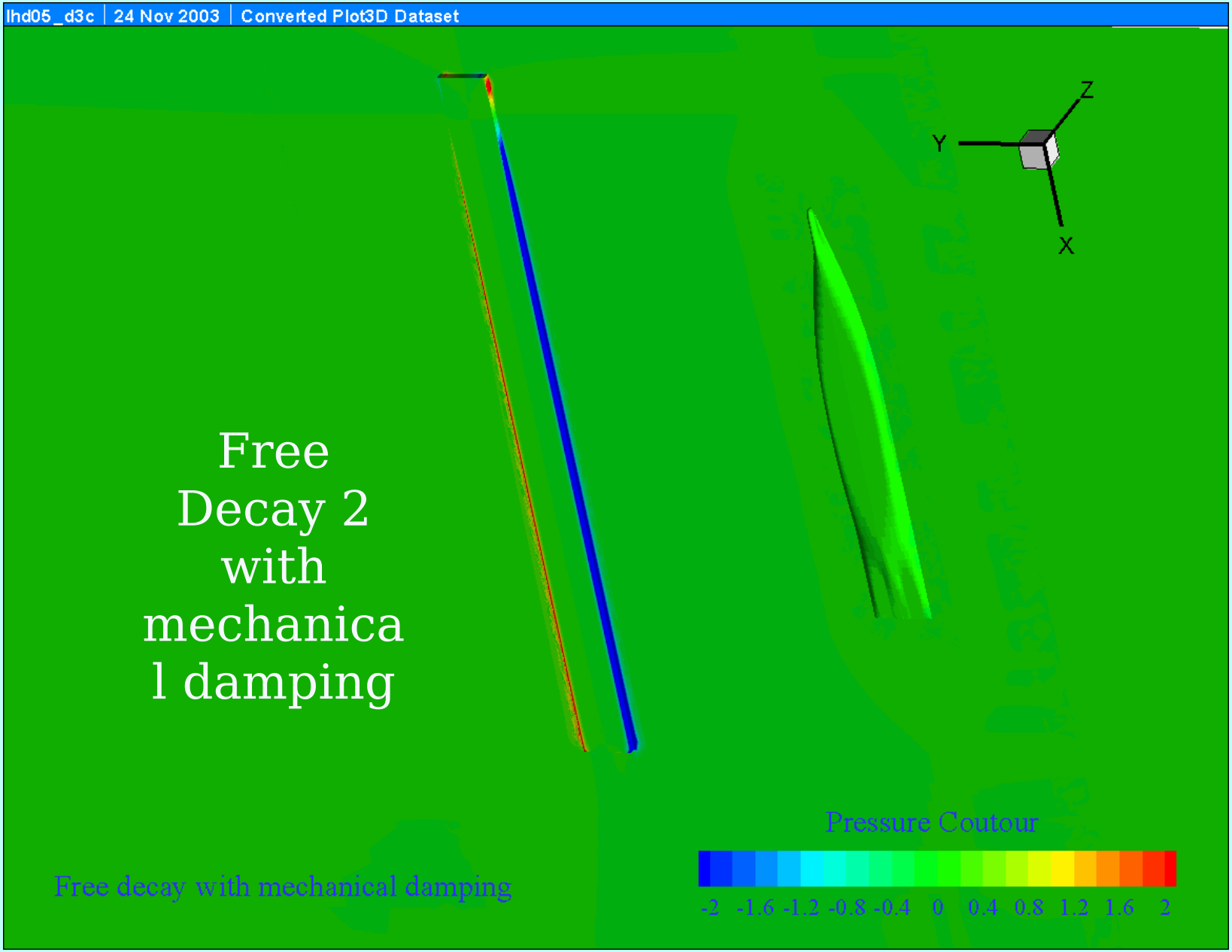


Validation 3: Free decay/Natural frequency



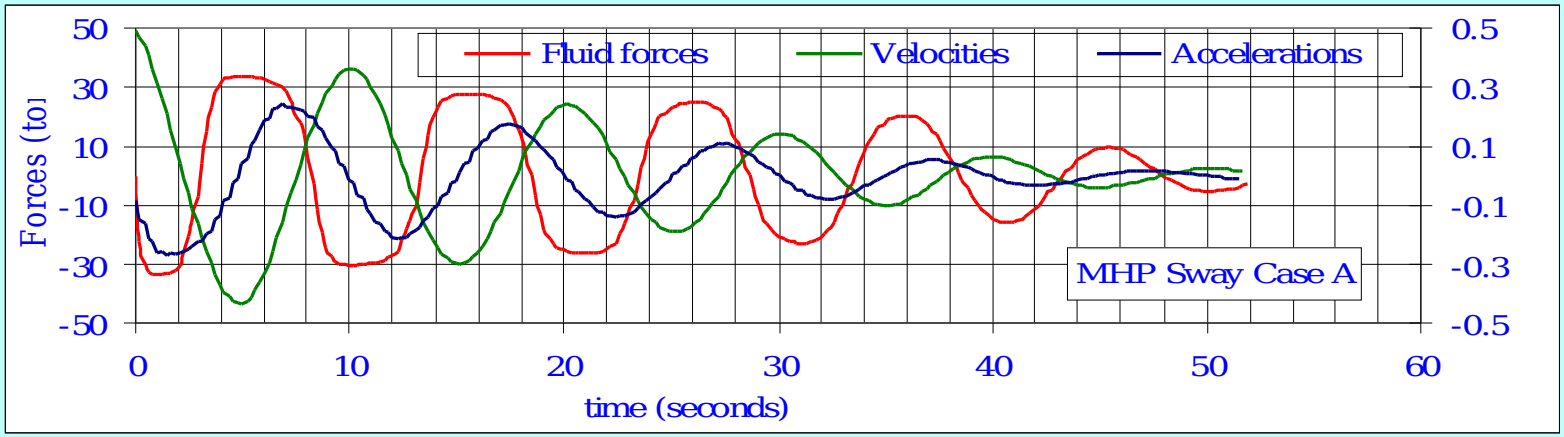


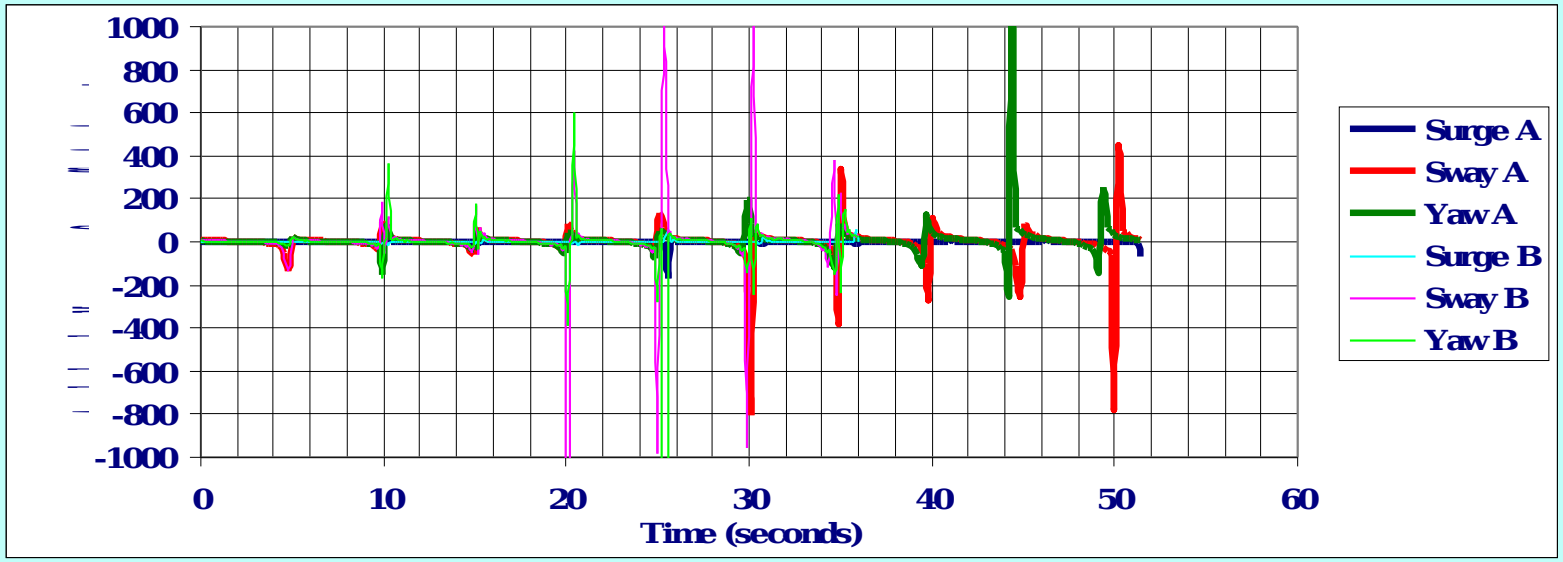
Case ID	ω_* (in the air) Undamped frequency			$\omega_{d'} = \omega_* * \sqrt{(1 - \eta^2)}$ theory (Equation xx)			ω_d Simmulated frequency			η Damping coefficient (Equation xxxx)		
	Surge	Sway	yaw	Surge	Sway	yaw	Surge	Sway	yaw	Surge	Sway	yaw
Case A	0.609	0.609	0.618	.609	.607	.617	.603	.607	.610	.0004	.0730	.0562
Case B	0.609	0.609	0.618	.609	.607	.617	.602	.604	.606	.0004	.0786	.0529


lhd05_d3c | 24 Nov 2003 | Converted Plot3D Dataset
Z
Y
X
Free
Decay 2
with
mechanica
l damping
Pressure Coutour
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2
Free decay with mechanical damping

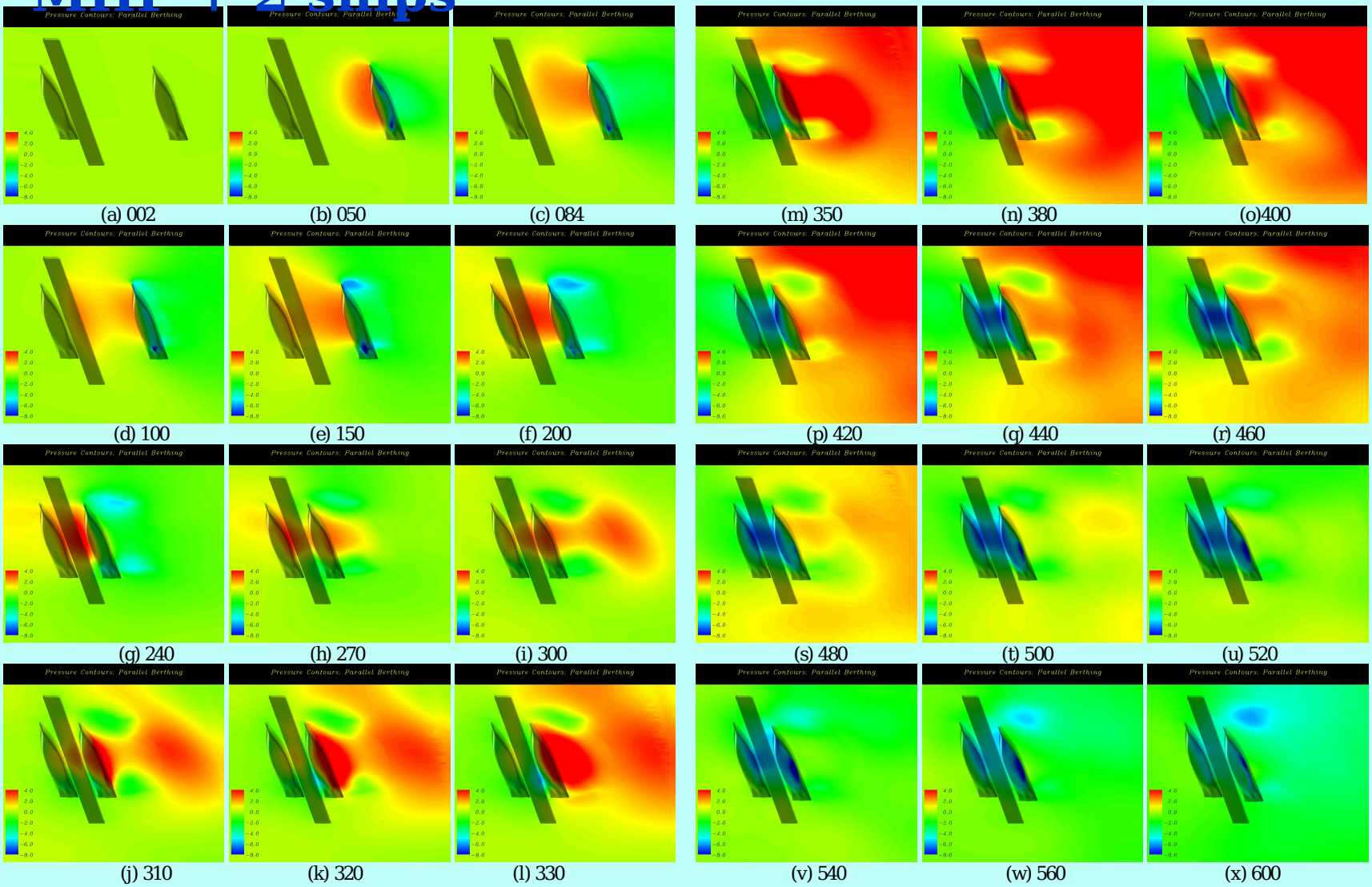
Nature of fluid reactions

Added mass ?





Hull and free surface pressure distribution: MHP + 2 ships



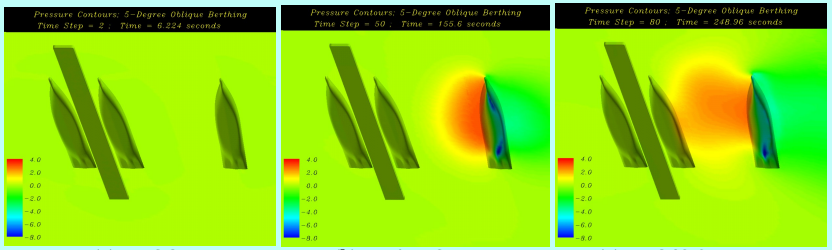
(a) 002 (b) 050 (c) 084 (m) 350 (n) 380 (o)400

(d) 100 (e) 150 (f) 200 (p) 420 (q) 440 (r) 460

(g) 240 (h) 270 (i) 300 (s) 480 (t) 500 (u) 520

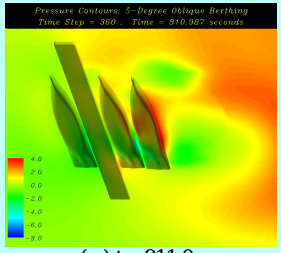
(j) 310 (k) 320 (l) 330 (v) 540 (w) 560 (x) 600

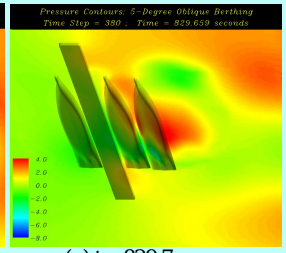
Hull and free surface pressure distribution: MHP + 3 ships

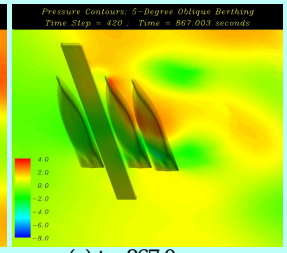

(a) t = 6.2 sec

(b) t = 155.6 sec

(c) t = 249.0 sec


(m) t = 811.0 sec


(n) t = 829.7 sec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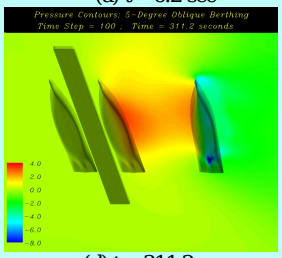
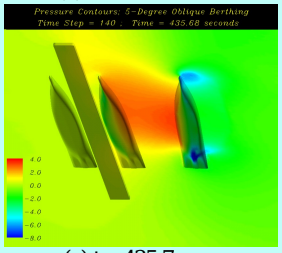

(d) t = 311.2 sec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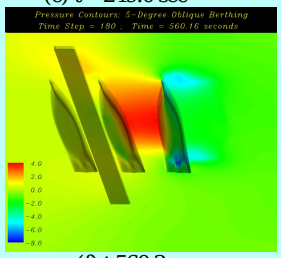
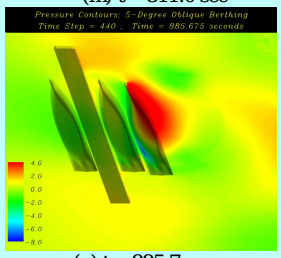

(f) t 560.2 sec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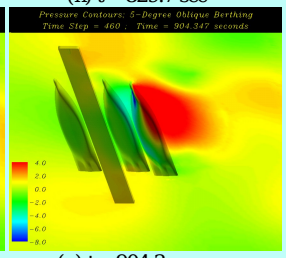
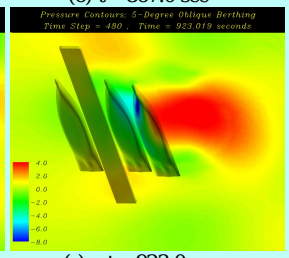
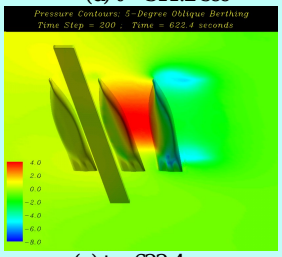

(q) t = 904.3 sec


(r) = t = 923.0 sec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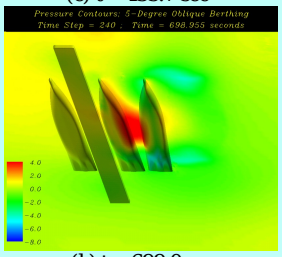
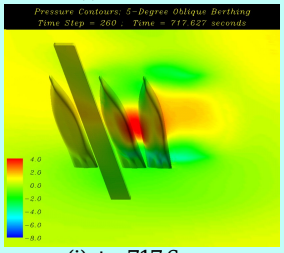
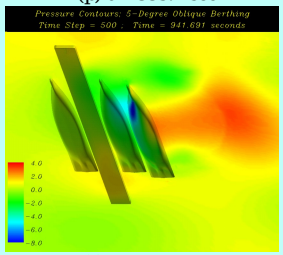

(h) t = 699.0 sec


(i) t = 717.6 sec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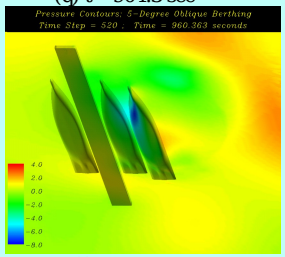
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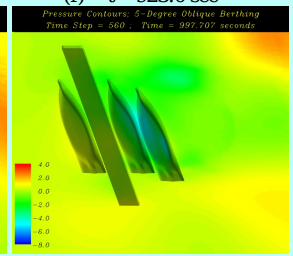
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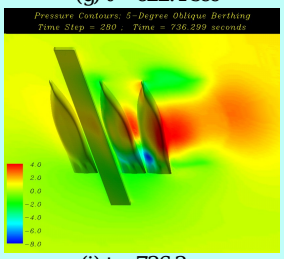
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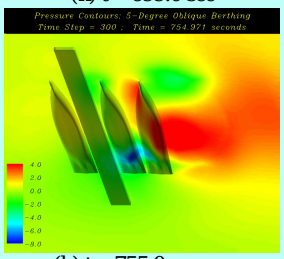
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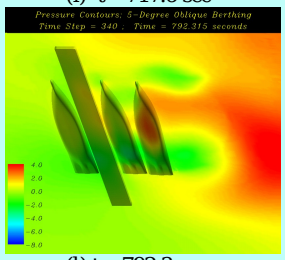
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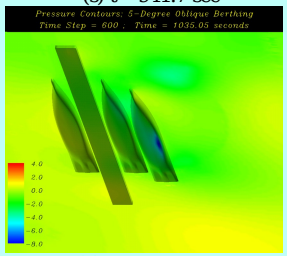
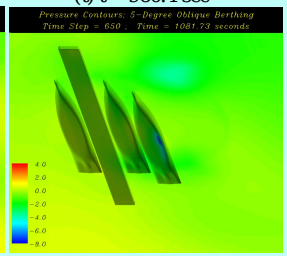
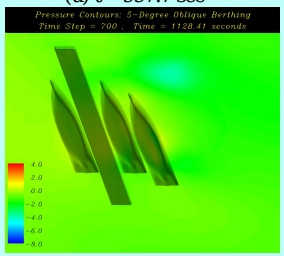

(v) t = 1035.1 sec


(w) t = 1081.73 sec


(x) t = 1128.41 sec

Provides a complete system description in detail

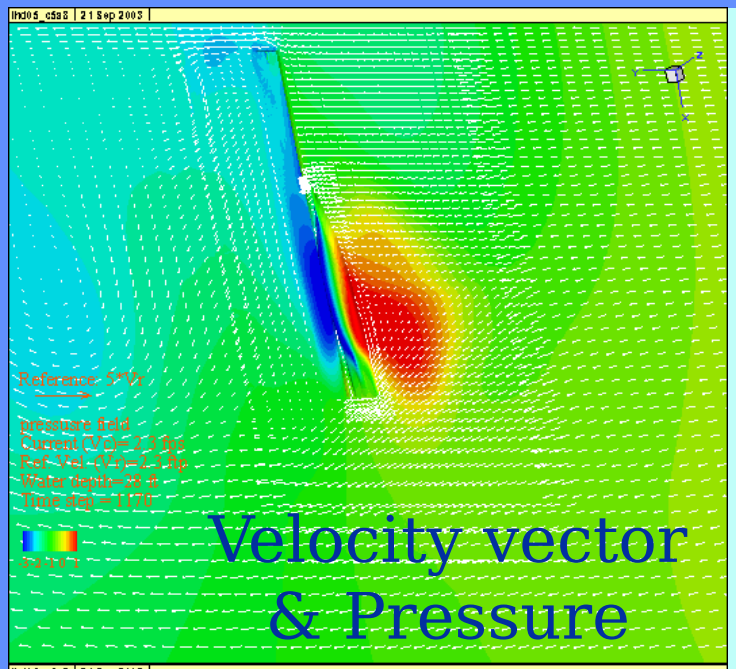
(in time domain throughout entire simulation duration)

Fluid

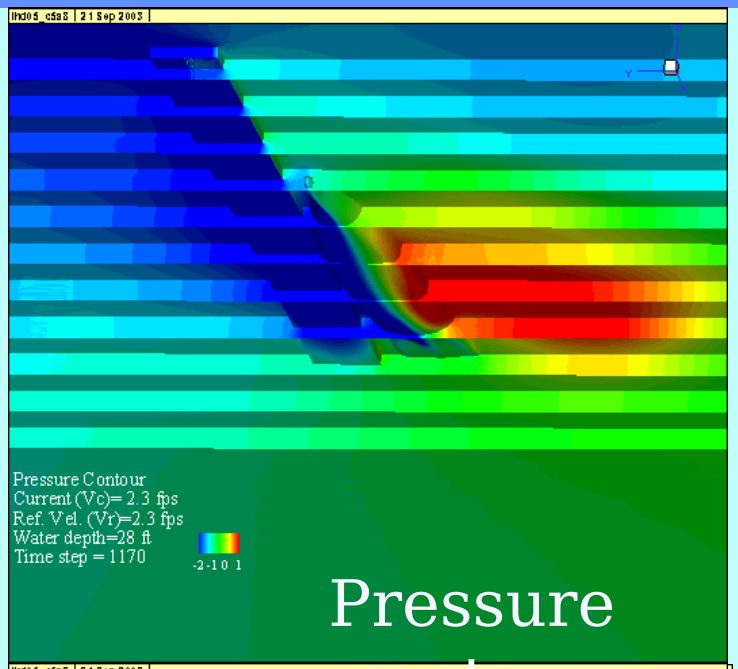
- Pressure
- Velocity (u, v, w)
- Density
- Vorticity
- Turbulence
- Surface waves

Ship/Structure

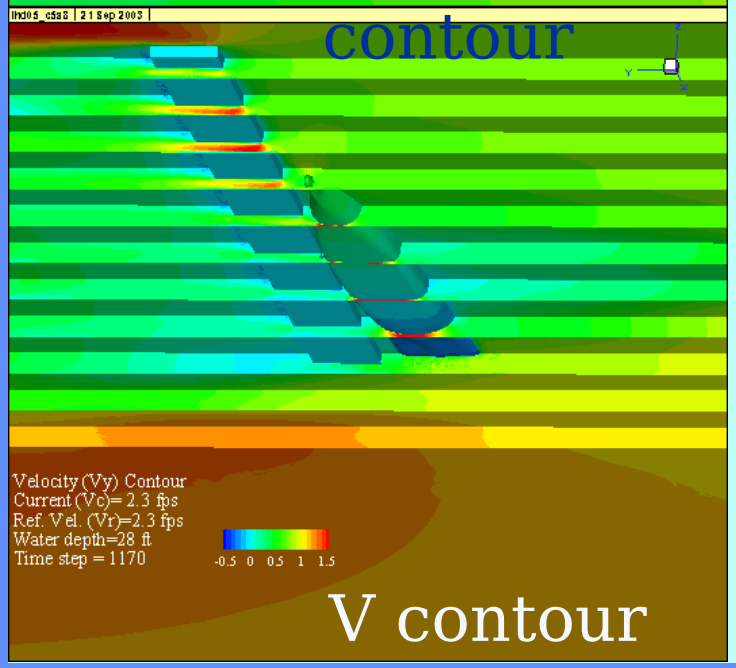
- Fluid forces
- Ship/Structure behaviors
- Relative motions
- Coupling forces
- Mooring reactions
- Overtopping/Green water



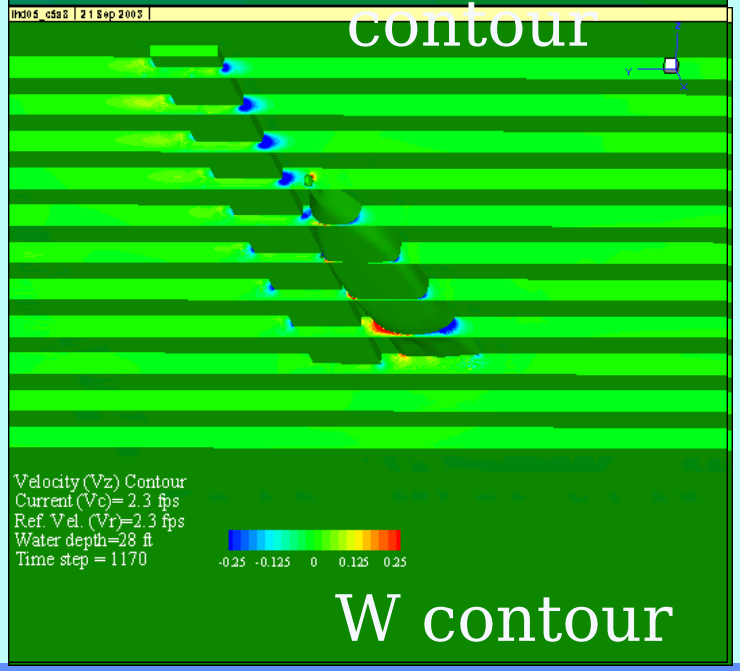
Velocity vector & Pressure contour



Pressure contour



V contour



W contour

CASE:LHD05

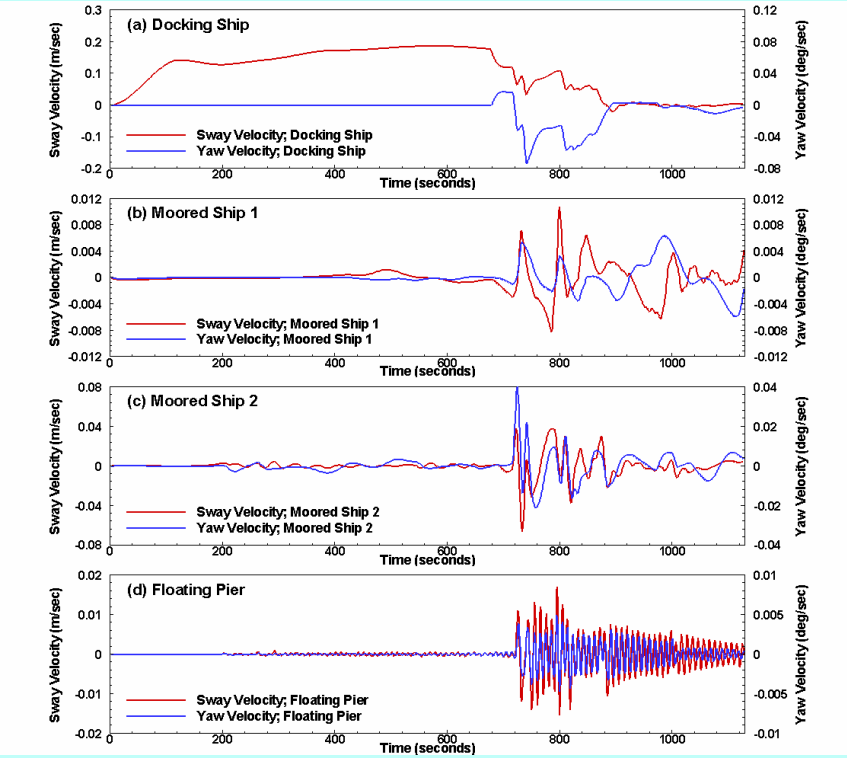
1SM_C5A8a

Water depth:28 feet

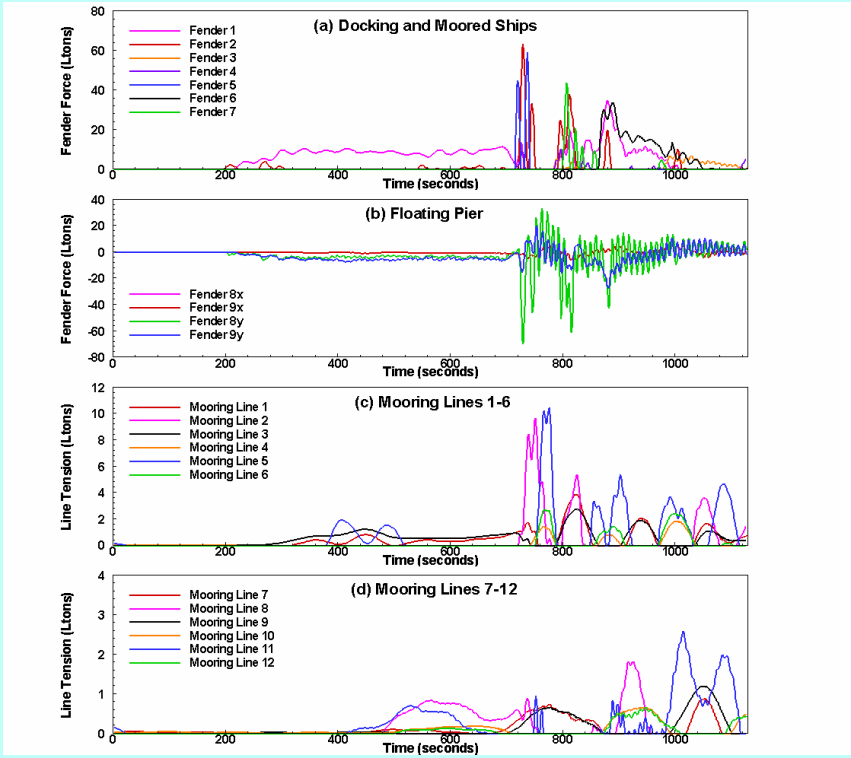
Current spd: 2.3 fps

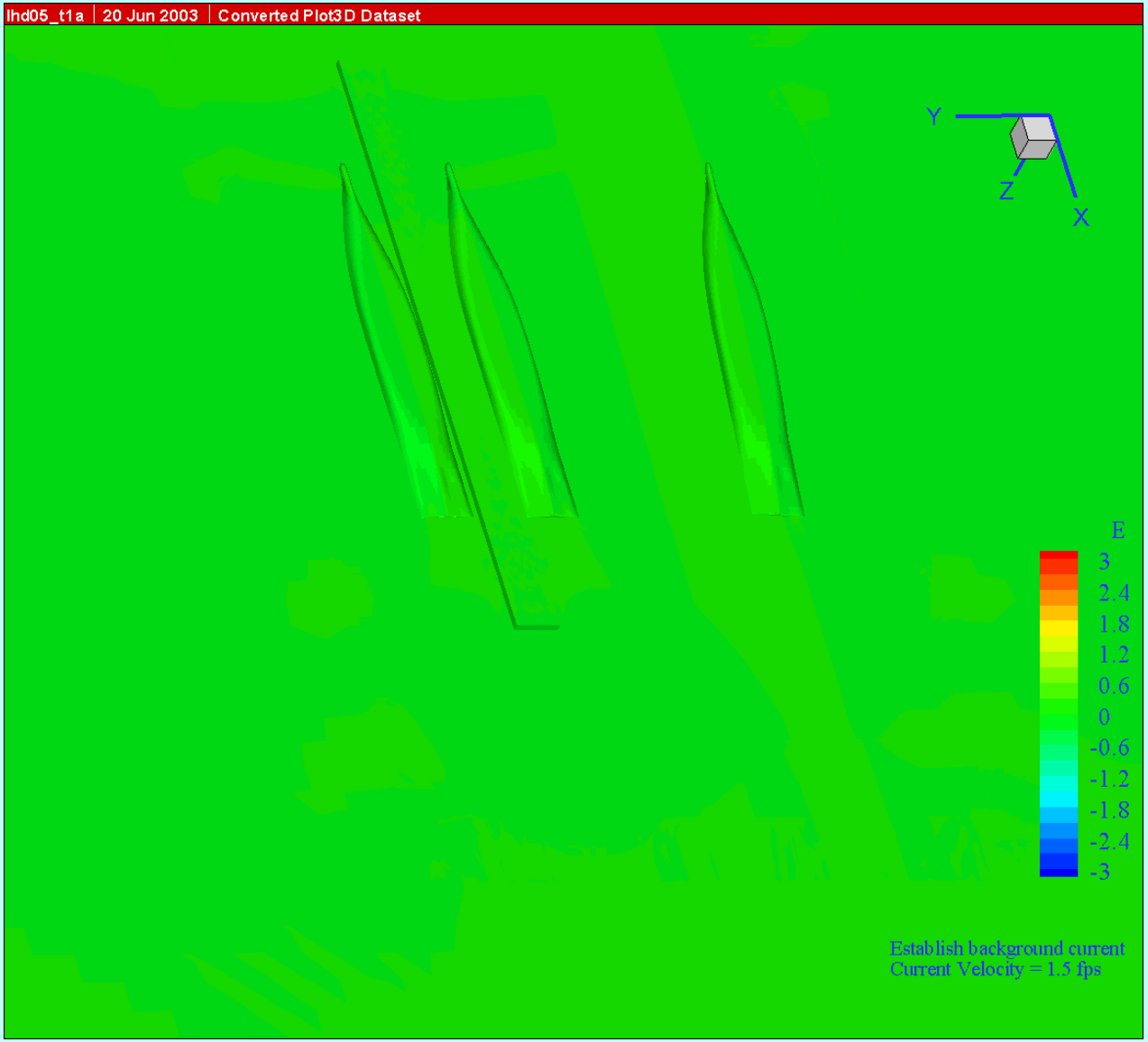
- pressure
- velocity (u,v,w)
- density
- vorticity
- turbulence

Vessel motions



Coupling forces





Parameters explored

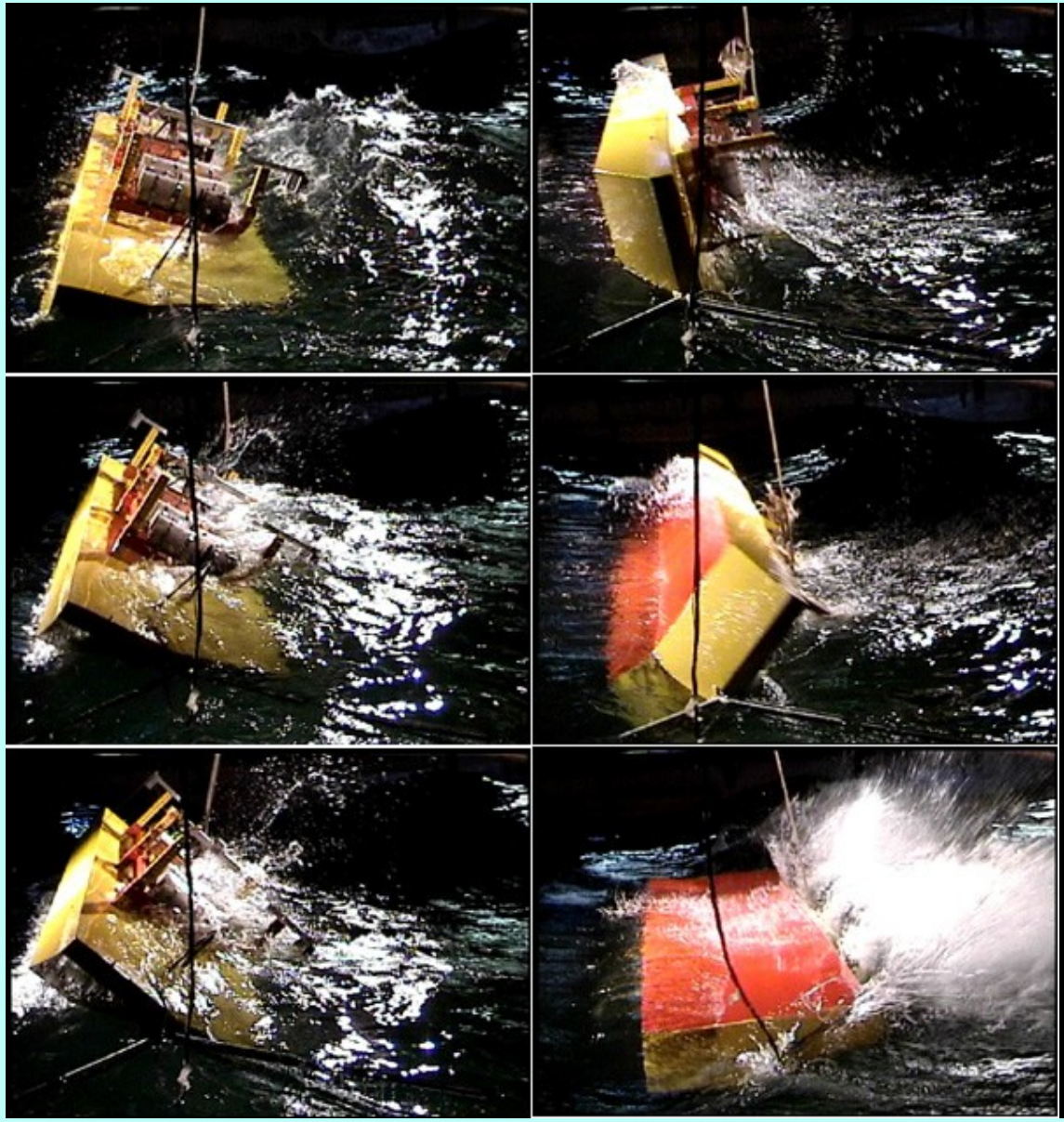
- Ship layouts
- Pier layouts
- Berthing procedures
- Coupling layouts
- Mooring features
- Water depths
- Tug thrust
- Current speeds
- Wind forces

Stability test - Fy96

Type: Froude model
Scale: 1/8 scale of ACBL
Scope: stability threshold
nonlinear factors

Test parameters

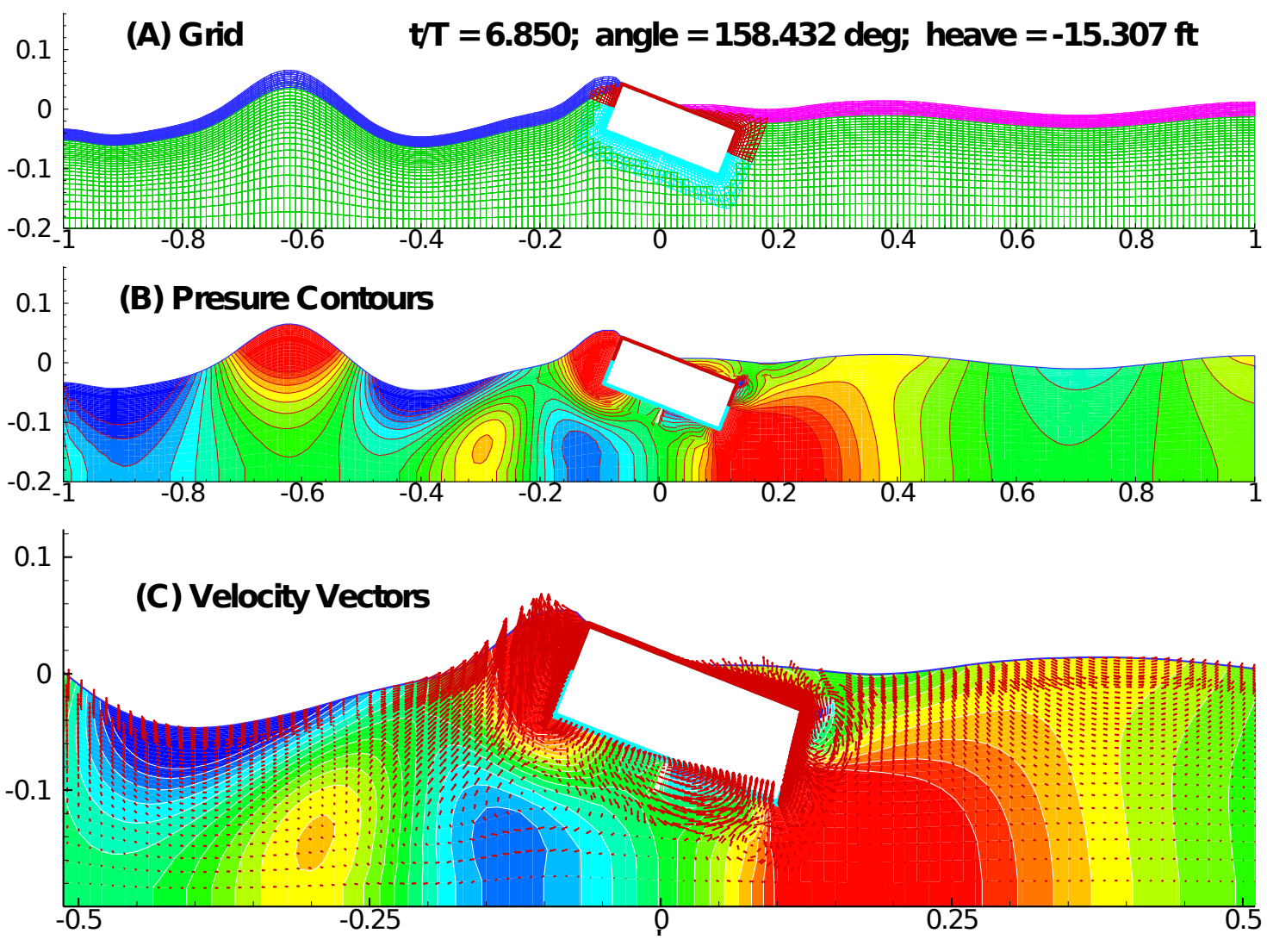
Waves: Swell 3-12 ft at 5-1
Storm SS4 - SS5
Heading: 0, 45, 90 deg.
Draft: 4 and 6 feet
C. G. : 9.13-11.30 ft above



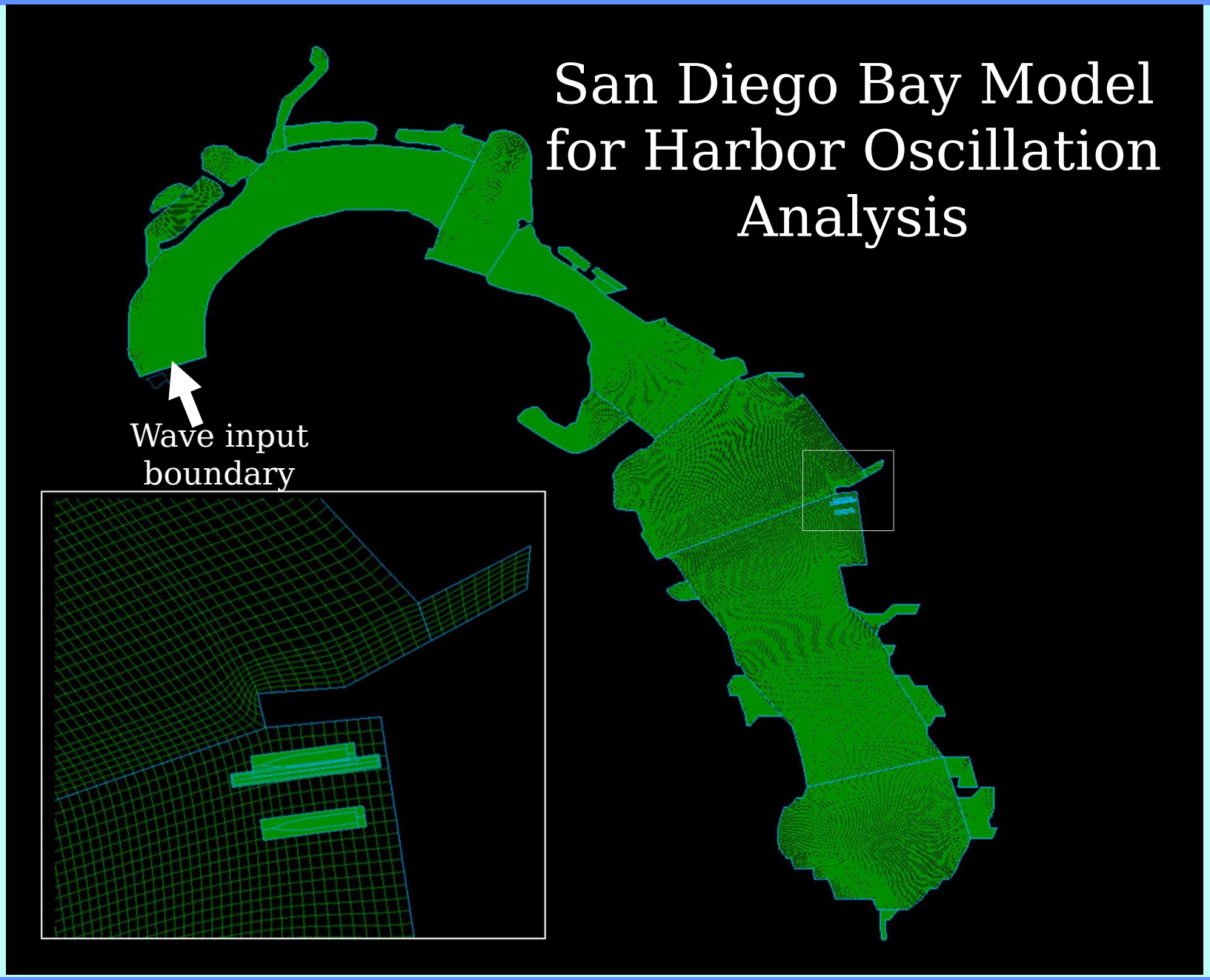
Video

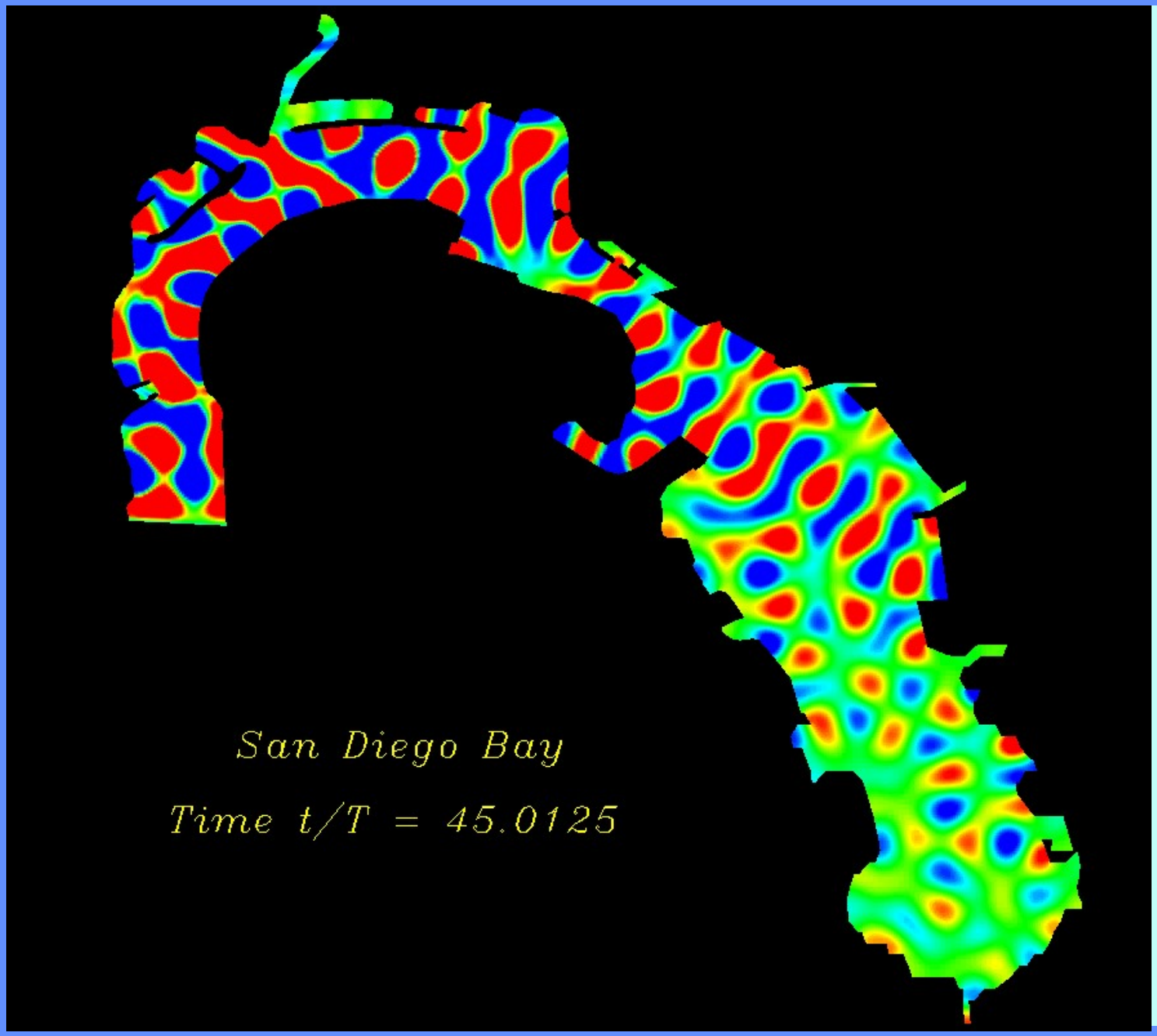
Barge capsizing: hydraulic model

Barge capsizing: numerical simulation



San Diego Bay Model for Harbor Oscillation Analysis





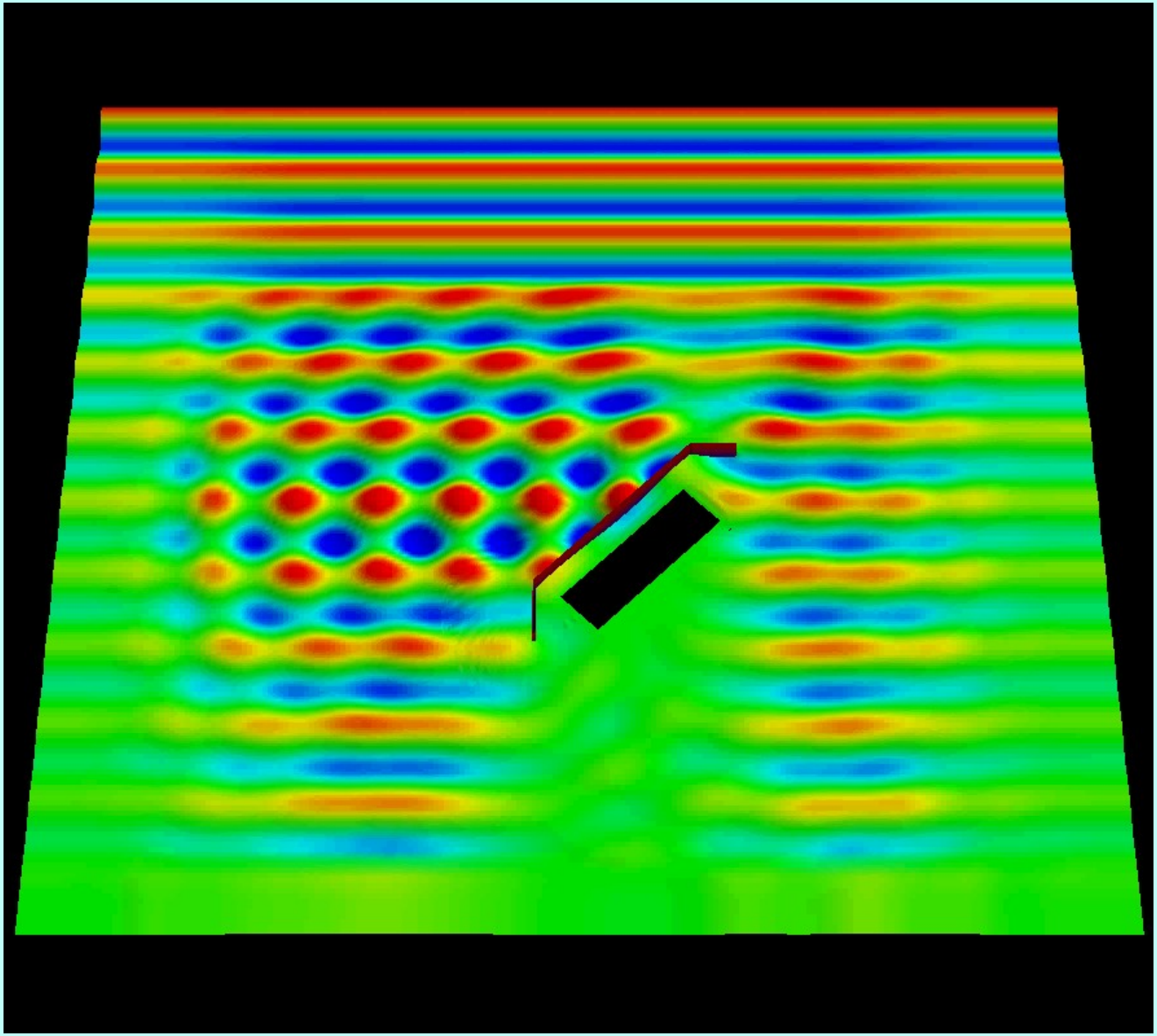
Wave transformation in San Diego Bay

(preliminary)

Wave length: 5000 ft

Water depth: 40 ft

Numeric al Tank



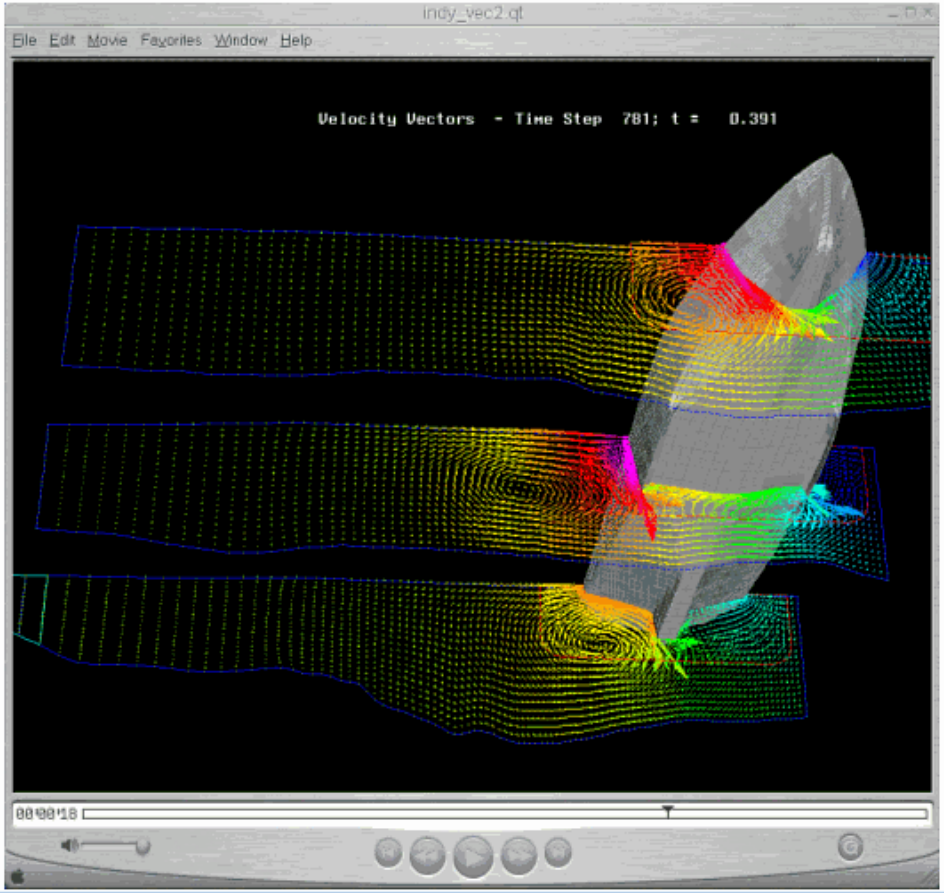
Summary

CFD simulation

- complements experimental and theoretical fluid dynamics
- provides high-fidelity, high-resolution insights
- addresses non-existence entities
- handles non-reproducible conditions
- pertains to the entire life cycle of a system
- reduces total ownership cost

Consider viscous codes if any of the following exists.

- shallow water
- transverse motion/Beam currents
- heavily coupled multi-body system

NAVFAC
Naval Facilities Engineering Command
Engineering Service Center

Q&A: